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The Efficacy of Bikram Yoga in Stressed and Sedentary Adults

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Statement of Authentication

I, Zoe Louise Hewett, hereby declare that the work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

Signed:

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Zoe Louise Hewett

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Statement of Contributions to Jointly Authored Works Contained Within

Manuscripts

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Abstract

Background: Cardiovascular disease (CVD) is the leading cause of death worldwide. It has been well documented that physical inactivity (sedentary lifestyle) and chronic psychosocial stress both contribute to the development of key CVD risk factors. CVD-related morbidity and mortality could likely be reduced if a larger proportion of the public were to adopt healthier lifestyle behaviours, including quality physical activity and effective stress management techniques.

Research Program: This research program was undertaken from March 2013 to May 2017. The research culminated in a randomised controlled trial (RCT) conducted across two Bikram yoga studios in the Australian Capital Territory (Canberra, ACT).

Aims: Overall, this research program aimed to investigate the effect of Bikram yoga on the physiological and psychological health outcomes in stressed and sedentary adults. Specifically, the aims were: (i) to critically review the existing literature on Bikram yoga and provide recommendations for future trials; (ii) to investigate the effect of a 16-week Bikram yoga intervention on the high-frequency (HF) power component of heart rate variability (HRV), secondary measures of HRV and associated CVD risk factors; (iii) to investigate the effect of a 16-week Bikram yoga intervention on measures of psychological health status; and (iv) to investigate predictors of and barriers to adherence to the 16-week Bikram yoga intervention.

Overview of Chapters: The background and aims of the research program, and general review of the literature are presented in chapters one and two, respectively. Chapter three contains a narrative review of the Bikram yoga literature which was published in *Evidence-*

based Complementary & Alternative Medicine in 2015. Previous studies that were published or discovered after the narrative review are included in the general literature review (chapter two). Previous RCTs suggest that Bikram yoga may improve fitness outcomes including strength, flexibility and balance, and reduces cortisol reactivity, distress tolerance and emotional eating. Uncontrolled trials suggest that Bikram yoga may improve blood lipids and arterial stiffness, reduce perceived stress, and may improve mindfulness and quality of life. Overall, the quality and depth of the current research is limited. Chapter four outlines the general methodology for the RCT implemented in this research program. Chapters five and six present findings from the 16-week Bikram yoga RCT on (i) the HF component of HRV, secondary HRV measures and associated CVD risk factors, and (ii) psychological health outcomes in sedentary and stress adults. Sixty-three participants (aged 37.2 ± 10.8 years, 79% women) were randomised to either the experimental group (three to five Bikram classes per week) or the no-treatment control group. No significant change was reported in the HF component of HRV ($p = 0.912$) or in any secondary physiological outcome measure. The experimental group reported reduced perceived stress ($p = 0.003$), increased general self-efficacy ($p = 0.034$) and exercise self-efficacy ($p = 0.003$), and improved general health ($p = 0.034$) and energy/fatigue ($p = 0.019$) domains of health-related quality of life (HRQoL). Higher adherence was associated with significant reductions in diastolic blood pressure ($p = 0.039$), body fat percentage ($p = 0.001$), fat mass ($p = 0.003$) and body mass index ($p = 0.05$), and perceived stress ($p = 0.03$), and increases in exercise self-efficacy ($p = 0.002$) and increases in several domains of HRQoL ($p \leq 0.022$). Chapter seven presents the findings from the investigation of factors contributing to adherence to Bikram yoga in stressed and sedentary adults. Twenty-nine participants (aged 38.2 ± 10.1 years, 79% women) were randomised to the experimental group. On average, participants attended 54% of the minimum prescribed (3 sessions/week) classes (26 ± 15 classes, range: 4 to 48 classes).

Higher adherence was associated with older age, less pain, fewer physical limitations, poorer blood lipid profile, and HRV (total power). In multi-variable analysis, three variables: age ($\beta = 0.492$, $p = 0.006$), HRV (total power) ($\beta = 0.413$, $p = 0.021$) and pain ($\beta = 0.329$, $p = 0.048$) remained significant predictors of adherence, explaining 41% of the variance. Self-report data indicated that main barriers to adherence were difficulty committing to the trial, lack of enjoyment of the intervention, and adverse events due to pre-existing conditions.

Conclusions: Chapter eight presents the overall thesis summary, conclusions and future research directions. In summary, this thesis has made a significant contribution to furthering the current understanding of Bikram yoga intervention in sedentary and stressed adults through a narrative review of existing research, and by conducting a rigorous RCT. The narrative review in chapter three revealed potential benefits of Bikram yoga on fitness outcomes, psychological outcomes, and some physiological outcomes in certain populations. The current body of literature exhibits a general weakness in methodology. Evidence from the 16-week RCT presented in chapters five and six reported little to no effect on HRV and CVD risk factors, and positive adaptation of several psychological health measures in sedentary and stressed adults, compared to no-treatment. A dose-response effect appears to exist, and as shown in chapter seven, adherence was influenced by several baseline characteristics, and inhibited by time constraints, enjoyment of Bikram yoga, and adverse events. Continued research via RCT design is required to investigate the effect of Bikram yoga in larger samples and higher risk populations, with consideration of potential barriers to adherence prior to intervention.

RCT Registration: Retrospectively registered with Australia New Zealand Clinical Trials Registry ACTRN12616000867493. Registered 04 July 2016. URL: http://www.anzctr.org.au/ACTRN12616000867493.aspx

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Abbreviations

Abbreviation	Full term
ACT	Australian Capital Territory
AIx	Augmentation index
ANCOVA	Analysis of covariance
ANS	Autonomic nervous system
BMI	Body mass index
CI	Confidence interval
CLBP	Chronic low back pain
CRP	C-reactive protein
CSE	Core self-evaluation
CVD	Cardiovascular disease
DASS-21	Depression-Anxiety-Stress Scale (21-item)
DXA	Dual-energy x-ray absorptiometry
ECG	Electrocardiogram
FMD	Flow-mediated dilation
HDL	High-density lipoprotein
HF	High frequency
HIV	Human immunodeficiency virus
HPA	Hypothalamic-pituitary axis
HRQoL	Health-related quality of life
HRV	Heart rate variability
hsCRP	High-sensitivity c-reactive protein
LF	Low frequency
LF:HF	Low-frequency to high-frequency ratio
LDL	Low-density lipoprotein
Ln	Natural logarithm
MET	Metabolic equivalent
NATA	National Association of Testing Authorities
NN	Normal-to-normal
PAR-Q	Physical Activity Readiness Questionnaire
η_p^2	Partial eta-squared
pNN50	Proportion of the number of pairs of successive NN intervals that differ by 50ms divided by the total NN intervals
PSS	Perceived stress scale
PTSD	Posttraumatic stress disorder
RCT	Randomised controlled trial
RMSSD	Root mean square of successive differences between adjacent NN intervals
RR	R-wave to r-wave
SD	Standard deviation
SDNN	Standard deviation of NN intervals
SNS	Sympathetic nervous system
SPSS	Statistical Package for the Social Sciences
TC	Total cholesterol

Chapter 1

Introduction

1.1 Background

Cardiovascular disease (CVD) is the leading cause of death worldwide, accounting for 46% of total deaths in 2012 (World Health Organisation, 2016). Traditional physiological CVD risk factors include hypertension, hyperlipidaemia, impaired glucose management and obesity (Yusuf et al., 2004). Inflammatory marker C-reactive protein (CRP) is also associated with CVD (McDade et al., 2006). It has been well documented that physical inactivity (sedentary lifestyle) (Katzmarzyk et al., 2009; Lee et al., 2012) and chronic psychosocial stress (Foss & Dyrstad, 2011) both contribute to the development of key CVD risk factors, including obesity and type 2 diabetes. Therefore, CVD-related morbidity and mortality could likely be reduced if a larger proportion of the public were to adopt healthier lifestyle behaviours, including quality physical activity and effective stress management techniques (APS, 2015; Hallal et al., 2012).

Yoga is an ancient system of practices based on the scientific principles of exercise, breathing and meditation, and philosophical beliefs (Borg-Olivier & Machliss, 2011). Many modern forms of yoga presented in class format are derived from the teachings in Patanjali's Yoga Sutras, which are based around an 8-limbed path of yoga (*ashtanga)* that leads to union of the individual self with the universal self (Iyengar, 1991). This union is found in the origin of the word yoga itself, which in Sanskrit means 'to yoke', or 'communion' (Iyengar, 1991). The 8-limbs of *ashtanga* yoga are *yama* (universal moral commandments), *niyama* (self-purification by discipline), *asana* (posture), *pranayama* (breath control), *pratyahara* (withdrawal of the mind from the senses), *dharana* (concentration), *dhyana* (meditation) and *samadhi* (individual becomes one with the universal self) (Iyengar, 1991). Yoga that emphasises the performance of *asanas* and *pranayama* is classified as *hatha* yoga (Borg-Olivier & Machliss, 2011). The practice of *hatha* yoga incorporates body, breath and mind together in the practice of *asana*, a combination that may effectively assist in the prevention and treatment of chronic disease and stress-related illness. Numerous investigations have documented the health-related benefits of several weeks to months of *hatha* yoga training (Chong et al., 2011; Jayasinghe, 2004; Ross & Thomas, 2010). However, fewer studies have focused on describing the effects of a specific style of *hatha* yoga, and the variable nature within styles and from class to class can make it challenging to do so (Innes et al., 2007; Sherman, 2012).

Bikram yoga is a standardised system of heated *hatha* yoga developed by Bikram Choudhury (Choudhury, 2007). Choudhury taught yoga in Bombay during the mid 1960's before developing a series of yoga *asanas* and breathing exercises for group-based practice that he believed would remedy many medical conditions that he saw as a teacher, such as heart disease, diabetes, arthritis, neurological diseases and back pain (Choudhury, 2007). In 1973, Choudhury opened the first Bikram yoga school in the United States (Choudhury, 2007) and today, there are yoga studios worldwide offering Bikram yoga classes including studios across Australia (Bikram Yoga, 2012). Each 90-minute class involves the performance of 26 beginner's *asanas* and two breathing exercises within a heated room (40.6°C and 40% humidity). In addition to the heated environment, the specific series of *asanas* and the instructional dialogue are key components of this practice. The series of *asanas* never changes, and the class is taught verbally using a learned dialogue rather than the teacher performing the *asanas* with the class. The class starts with a breathing exercise, continues with standing *asanas*, followed by floor-based *asanas*. *Savasana* (relaxing lying supine) which separates the standing and floor *asanas*, is used between each *asana* in the floor series, and is also used to conclude the class directly after a second breathing exercise.

1.2 Review of the literature

Several studies have investigated the effects of Bikram yoga practice on health-related outcomes using various study designs including a limited number of randomised controlled trials (RCTs) (Abel et al., 2012; Hart & Tracy, 2008; Hewett et al., 2011; Hunter et al., 2013; Hunter et al., 2013; Kudesia & Bianchi, 2012; Sangiorgio et al., 2014; Tracy & Hart, 2013). However, to our knowledge, these studies have never been synthesised and critiqued. Accordingly, there is no consensus in the scientific literature regarding the effectiveness of Bikram yoga on health outcomes, or directions for future research. Therefore, a comprehensive and critical review of the literature is necessary to summarise studies that have investigated the effect of Bikram yoga practice on health-related outcomes, and elucidate gaps in the body of research, and provide recommendations for future trials.

1.3 Effect of Bikram yoga on heart rate variability and associated CVD risk factors

Chronic psychological stress is associated with increased risk of CVD and associated mortality (Dishman et al., 2000; Foss & Dyrstad, 2011; Thayer & Lane, 2007). Under stressful conditions, the sympathetic nervous system (SNS) mediates neuroendocrine changes via the hypothalamic-pituitary-adrenal (HPA) axis (Bose et al., 2009; Charmandari et al., 2005). This SNS activation response includes the release of stress hormones which in turn increase heart rate, blood pressure, and blood lipid and glucose concentrations, preparing the body for physical exertion. Chronic SNS activity, via this mechanism, can contribute to atherosclerosis and CVD, particularly in individuals who are physically inactive (sedentary) (Chandola et al., 2008; Chrousos, 2000).

Heart rate variability (HRV) is a non-invasive physiological measure of stress. Low HRV is associated with a reduced capacity to adjust to environmental demands (Ryan et al., 2011; Thayer & Lane, 2009) and increased risk of CVD and mortality (Nolan et al., 1998;

Thayer & Lane, 2007, 2009). Moreover, low HRV is often observed in individuals who are sedentary (Dietrich et al., 2008), overweight-obese (Andrew et al., 2013; Lampert et al., 2008) and psychologically stressed (Dishman et al., 2000). Vagal activity is reflected in the high frequency (HF) spectral power component of HRV (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996).

Several studies have reported that *hatha* yoga can reduce perceived stress (Chong et al., 2011) and salivary cortisol, a main effector of the SNS and HPA axis pathways (Banasik et al., 2011; Rocha et al., 2012; West et al., 2004). Controlled and uncontrolled trials have also reported that a single session of *hatha* yoga can acutely increase the HF power component (reflects vagal activity) of HRV (Huang et al., 2013; Papp et al., 2013; Satyapriya et al., 2009; Sawane & Gupta, 2015). However, the chronic effects of *hatha* yoga training on resting HRV remain inconclusive due to a lack of robust clinical trials (Posadzki et al., 2015).

The heated environment is a cornerstone feature of Bikram yoga and may aid in its effectiveness in improving HRV and abating CVD risk factors. Although it is difficult to directly compare other heated therapy conditions to Bikram yoga conditions, previous research suggests that heat exposure may be beneficial to health. For example, recent prospective data indicates that more frequent sauna bathing is associated with reduced risk of sudden cardiac death, coronary heart disease, and all-cause mortality in males (Laukkanen et al., 2015). Further, preliminary evidence suggests that thermal exposure (sauna bathing and spa treatment) may lead to increased resting HRV in healthy subjects and athletes (Corsini et al., 2015; Stanley et al., 2015). To date, no study has investigated the effect of Bikram yoga on any HRV outcomes alongside associated CVD risk factors (Hewett et al., 2015).

1.4 Effect of *hatha* yoga on measures of psychological health status

Studies have shown that psychological stress can increase the risk of CVD and associated mortality (Chrousos, 2000). Exercise is one of the more effective techniques to reduce psychological stress (Australian Psychological Society, 2015), yet those without established exercise habits tend to decrease physical activity in response to stress compared to habitual exercisers, who are more likely to use exercise to manage stress (Stults-Kolehmainen & Sinha, 2014). High stress is also associated with low self-efficacy (Yu et al., 2015), an attribute which contributes to exercise uptake and adherence (Sherwood & Jeffery, 2000). Low self-efficacy may also mediate other adverse psychological effects that arise from stress including depression (Sawatzky et al., 2012). The inability to manage stress has also been associated with lower health-related quality of life (HRQoL) (Faul et al., 2010).

Hatha yoga, a specific form of exercise has been shown to reduce perceived psychological stress, improve QoL and improve self-efficacy (Bryan et al., 2012; Chong et al., 2011; Lau et al., 2015; Tekur et al., 2010; Yang et al., 2011). Eight weeks of Bikram yoga may also reduce perceived stress and improve HRQoL (Hewett et al., 2015; Hunter et al., 2016). In addition to the components of *hatha* yoga including breath awareness, the heat may also contribute to improving perceived psychological stress and related mental-health outcomes. Studies have shown that sweat-practices, which involve exposure to heated environments such as sauna bathing and sweat lodges, can induce relaxation, and have a positive effect on hyperactivity, mood and stress (Eason et al., 2009). However, no RCT to date has specifically investigated the effect of Bikram yoga on perceived stress, or associated factors, such as self-efficacy and HRQoL, in a cohort of stressed and sedentary adults (Hewett et al., 2015).

1.5 Adherence to Bikram yoga intervention

Adherence to an exercise intervention is essential for the dose-response adaptation of health outcomes (American College of Sports Medicine, 2010). Bikram yoga consists of beginner-level *asanas* making it a suitable activity for sedentary, yoga-naïve participants, however, all interventions pose challenges regarding intervention adherence, particularly in sedentary populations. In addition to being sedentary, cohorts at risk for chronic disease may have other characteristics that act as barriers to traditional exercise uptake and adherence such as obesity, low self-efficacy or stress (Sherwood & Jeffery, 2000). Previous Bikram yoga trials have reported that dropouts were attributed to time commitments and lack of interest in the intervention (Hewett et al., 2011; Hunter et al., 2017; Hunter et al., 2016; Tracy & Hart, 2013), and tolerance to distress has been shown to predict adherence in some women (Baird et al., 2016), however, factors specifically affecting adherence to Bikram yoga have not yet been fully explored. Elucidating barriers to adherence to Bikram yoga intervention, and developing strategies to overcome them, may lead to improved adherence and improved adaptation of physiological and psychological outcomes.

1.6 Research program

This research program was undertaken from March 2013 to May 2017. The research culminated in a RCT conducted across two Bikram yoga studios in the Australian Capital Territory, i.e. Bikram Yoga Canberra and Bikram Yoga Kingston.

Rolling recruitment occurred between August 2014 and September 2015. The principal investigator and one PhD supervisor collected all baseline, midpoint and completion data at the University of Canberra and via email. The intervention was delivered by the certified Bikram yoga instructors at the respective studios. The candidate, also a certified Bikram yoga instructor, delivered some classes throughout the intervention. After the conception and design of this RCT, the principal investigator became a co-owner of Bikram Yoga Kingston.

1.7 Aims

The overall aim of this project was to build upon and strengthen the current quality of Bikram yoga research by reviewing the literature and implementing a RCT to evaluate the effect of Bikram yoga intervention on physiological and psychological health outcomes in sedentary and stressed adults. An additional aim was to investigate factors contributing to Bikram yoga adherence, to facilitate greater uptake in future RCTs.

Specific aims:

1. Critically review and summarise the existing literature on Bikram yoga and provide recommendations for future trials.

2. Investigate the effect of a 16-week Bikram yoga intervention on the high-frequency HF power component of HRV, secondary measures of HRV, and associated CVD risk factors (i.e. haemodynamic, anthropometric and haematological).

3. Investigate the effect of a 16-week Bikram yoga intervention on measures of psychological health status (i.e. psychological stress, self-efficacy, quality of life).

4. Investigate predictors of and barriers to adherence to the 16-week Bikram yoga intervention.

Chapter 2

General Review of the Literature

2.1 Global incidence and consequence of CVD

Cardiovascular disease (CVD) accounted for almost half of total deaths worldwide in 2012 (World Health Organisation, 2011). Further, CVD accounted for 37% of deaths in those under 70 years of age, also knowns as premature deaths (World Health Organisation, 2011). There are major economic and societal consequences associated with the CVD pandemic. For example, estimates from the US and Australia suggest that overweight-obesity, a well-established CVD risk factor, results in annual costs of approximately $113.9 billion and $56 billion, respectively (Colagiuri et al., 2010; Tsai et al., 2011). CVD and associated risk factors, such as overweight-obesity, appear to present a significant challenge to global health and prosperity in the coming decades (Hallal et al., 2012).

2.1.1 Sedentary lifestyle and CVD

There is a dose-response relationship between sedentary lifestyle and CVD (Katzmarzyk et al., 2009) and between sedentary lifestyle and all-cause mortality (Chau et al., 2013). One estimate suggests a 25% reduction of inactivity could prevent 1.3 million annual deaths worldwide, including deaths attributed to CVD or underlying risk factors, including type-2 diabetes (Lee et al., 2012). The same study (Lee et al., 2012) reports physical inactivity to be comparable to smoking and obesity as a risk factor for mortality. Physical activity is widely accepted as a preventative treatment for CVD risk (Thompson et al., 2003). Morbidity, mortality and health care costs would likely be reduced if a larger proportion of the public were to adopt a healthier lifestyle involving quality physical activity (Ding et al., 2016). Throughout this thesis, sedentary lifestyle will be defined as failing to reach the American College of Sports Medicine's minimum recommendation of ≥150 mins of moderate intensity exercise per week (American College of Sports Medicine, 2006).

2.1.2 Psychological stress and CVD

Chronic psychological stress is also associated with increased risk of CVD and associated mortality independent of traditional CVD risk factors (Dishman et al., 2000; Foss & Dyrstad, 2011; Thayer & Lane, 2007). During times of stress, the sympathetic nervous system (SNS) mediates neuroendocrine changes via the hypothalamic-pituitary-adrenal (HPA) axis (Bose et al., 2009; Charmandari et al., 2005). This 'fight-or-flight' response increases heart rate, blood pressure, and blood lipid and glucose concentrations, which can contribute to atherosclerosis and CVD over time, particularly in individuals who are physically inactive (Chandola et al., 2008; Chrousos, 2000). Interventions targeting physical activity and stress reduction together may be particularly effectively in reducing CVD morbidity and mortality.

2.2 *Hatha* yoga

Yoga is an ancient system of practices based on the scientific principles of exercise, breathing and meditation, combined with philosophical beliefs (Borg-Olivier & Machliss, 2011). Archaeological data suggest that yoga can be traced back at least 3,500 years to the Indus Valley Civilization (2600–1900 BCE) (Goldberg, 2007), though some authors suggest more ancient origins (Hewitt, 1990; Tsarion, 2008). Participation in yoga has increased greatly in recent decades with records from 2012 showing that the prevalence of yoga use in the United States general population increased to 8.9% from 5.1% in 2002 (Cramer et al., 2016). Yoga/Pilates use by male and female Australians doubled from 1.5% to 3.5% (Vergeer et al., 2017).

There are many different styles of yoga practiced in the West (e.g. Jivamukti, Iyengar, Power, Kundalini, Ashtanga, Bikram, Yin), and the majority emphasise the performance of physical postures (*asanas*), and can therefore be classified as *hatha* yoga (physical yoga) (Borg-Olivier & Machliss, 2011). *Hatha* yoga incorporates both physical activity and stress-reducing techniques (e.g. breath awareness and control) into the same activity, which may be effective for the prevention and potentially treatment of stress- and physical inactivity-related chronic diseases. Numerous investigations have documented the health-related benefits of several weeks to months of *hatha* yoga training (Chong et al., 2011; Jayasinghe, 2004; Ross & Thomas, 2010).

2.2.1 Effect of non-Bikram *hatha* yoga on haemodynamic CVD risk factors

Hypertension with advancing age is caused by progressive atherosclerosis which contributes to arterial stiffness (Romney & Lewanczuk, 2001; Vlachopoulos et al., 2010; Weber et al., 2004). Several studies have examined the effect of *hatha* yoga on blood pressure in unhealthy populations. A large RCT (n = 170) investigated the effect of 35-40 minutes of *hatha* yoga, five days per week for six months, on blood pressure and other CVD risk factors in male and female patients with coronary artery disease (Pal et al., 2011). Systolic ($p = 0.002$, -11.02 ± 9.46mmHg) and diastolic ($p = 0.009$, -8.85 ± 7.92mmHg) blood pressures were both significantly reduced in the experimental group (medication plus yoga) compared to the control group (medication only). This beneficial effect of hatha yoga on elevated blood pressure has been noted in other studies. For example, an RCT (n = 50) in adults living with the human immunodeficiency virus (HIV) and at risk for hypertension (120-139/80-89mmHg) also reported a significant reduction in systolic (-5 ± 2mmHg) and diastolic (-3 ± 1mmHg) blood pressures ($p = 0.04$) in the experimental group compared to control (usual care) after five months of *hatha* yoga practice, comprising of 60 minutes each session, two to three sessions per week (Cade et al., 2010). Moreover, a study limited to patients with diagnosed hypertension (n = 33) noted reduced systolic blood pressure ($p < 0.05$) in the experimental group compared to the control (usual care) after four months of

90-minute *hatha* yoga classes three times per week in a controlled trial (Mizuno & Monteiro, 2013). By contrast, trials investigating the effect of 60-90 minutes of *hatha* yoga performed one to three sessions per week for 8-16 weeks in normotensive (< 120/< 80mmHg) healthy adults did not report reductions in blood pressure (Granath et al., 2006; Smith et al., 2007). These findings support those reported in several recent systematic reviews and meta-analyses which suggest that, despite encouraging findings, the effect of *hatha* yoga on hypertension is not conclusive (Cramer et al., 2014; Posadzki et al., 2014; Tyagi & Cohen, 2014). Further, the methodology and reporting of trials has been reported to be of poor quality in general (Cramer et al., 2014; Posadzki et al., 2014; Tyagi & Cohen, 2014). Hence, there is a need to conduct better quality research in to develop a more thorough understanding of the effect of *hatha* yoga practice on hypertension.

Hypertension contributes to arterial stiffness, which increases CVD risk and is a predictor of all-cause mortality (Vlachopoulos et al., 2010). A 12-week RCT (n = 60) in older men with increased pulse pressure reported that *hatha* yoga 60 minutes per day, six days per week, significantly improved brachial-ankle and carotid-femoral pulse wave velocities ($p = 0.002$; $p < 0.001$) and arterial stiffness index at the tibial artery and brachial artery ($p < 0.001$; $p = 0.032$) compared to a brisk walking control group (Patil et al., 2015). In patients with coronary artery disease, a 6-week uncontrolled trial (n = 33) reported improved ($p = 0.09$) endothelial function (brachial artery vasodilation) after 1.5 hours of *hatha* yoga and meditation three times per week (Sivasankaran et al., 2006). By contrast, an RCT (n = 34) reported no effect from 8 months of *hatha* yoga for 60 minutes twice per week on arterial compliance in premenopausal women compared to no-treatment control (Kim et al., 2012). Further, an uncontrolled trial (n = 13) reported no changes in arterial stiffness after 12 weeks of 75-minute long beginner's *hatha* yoga classes, two or more times per week in apparently healthy, middle-aged adults (Hunter et al., 2013). Arterial stiffness has also been examined in a cross-sectional study in apparently healthy adults comparing *hatha* yoga practitioners (n = 8), aerobic exercisers (n = 10) and sedentary adults (n = 8) (Duren et al., 2008). Preliminary findings reported that both the yoga and exercise groups combined demonstrated reduced arterial stiffness when compared to the third, sedentary group (Duren et al., 2008). Aerobic exercise in the yoga group, however, was not controlled for, and therefore, an independent effect of *hatha* yoga, however, could not be determined. By contrast, a cross-sectional study also in apparently healthy adults found no differences in arterial stiffness comparing those engaged in *hatha* yoga (n = 23) with sedentary counterparts (n = 28) (Hunter et al., 2013). It is not surprising that arterial stiffness does not appear to differ between groups in healthy cohorts. Based on these few studies, *hatha* yoga does not consistently improve measures of arterial stiffness, especially in apparently healthy adults. The lack of consistent effects across studies may be due to the different levels of health status of the cohorts investigated, and the intensity of the style of yoga relative to the level of health of the cohort. Further, considering that the optimal yoga dosage necessary for positive adaptation of physiological outcomes is relatively unknown, two or less classes per week may be insufficient to elicit adaptation in arterial stiffness (Sherman, 2012; Ward et al., 2014).

2.2.2 Effect of non-Bikram *hatha* yoga on haematological CVD risk factors

Impaired fasting blood glucose and dyslipidaemia are traditional CVD risk factors as well as components of metabolic syndrome (Alberti et al., 2009). In adults with type-2 diabetes (n = 277) a 9-month RCT compared the effect of a *hatha* yoga-based lifestyle intervention with an exercise-based lifestyle intervention (walking, physical training exercises and rest, comparable to intensity of yoga intervention) (Nagarathna et al., 2012). For 12 weeks *hatha* yoga was delivered by instructors five days per week for 60 minutes and for the remaining 24 weeks of the intervention participants were required to complete 60 minutes of yoga daily. Yoga-based intervention reduced LDL ($p = 0.003$), increased HDL ($p = 0.007$) and reduced fasting blood glucose ($p = 0.016$) compared to the exercise-based control group. Triglycerides, total cholesterol and haemoglobin A1c (HbA1c) were significantly reduced in both groups, however no differences were found between groups. These findings suggest that *hatha* yoga was as effective, and in some cases more effective than, exercise-based intervention for improving haematological CVD risk factors. In support of these findings, another large RCT (n = 173) investigated the effect of 12 weeks of *hatha* yoga intervention for 60 minutes per week in adults with and without metabolic syndrome (Lau et al., 2015). The yoga group reduced fasting blood glucose ($p < 0.01$) and triglycerides ($p < 0.05$) compared to the control group, however HDL did not improve. A recent systematic review also reported that yoga intervention in patients with coronary heart disease or type-2 diabetes, in conjunction with standard medication, may significantly improve LDL (-0.66 mmol/L), HDL (0.176 mmol/L), total cholesterol (-1.02 mmol/L) and triglycerides (-1.42 mmol/L) compared to non-exercise control groups (Chu et al., 2016). An earlier review also supports these findings by reporting that *hatha* yoga can significantly reduce HbA1c (-0.45%) and, in type-2 diabetics only, significantly reduce fasting blood glucose in (-1.41 mmol/L) (Cramer et al., 2014). Both reviews acknowledge methodological limitations to the trials reviewed, including small sample sizes and lack of standardised reporting of *hatha* yoga style and components (Chu et al., 2016; Cramer et al., 2014). Alternatively, a smaller 3-month pilot *hatha* yoga RCT (two classes per week, n = 23) reported no significant adaptation of fasting blood glucose, LDL and HDL in adults with high risk of diabetes engaging in the intervention as compared with an education-only control group (Yang et al., 2011). The small sample size of this pilot study and the limited frequency of classes per week may contribute to the lack of positive findings. According to a cross-sectional report, men and women engaged in regular yoga practice for longer than a year (n = 61) have significantly better indices of glucose control (i.e. fasting blood glucose, insulin, homeostasis model assessment of insulin resistance) than their non-yoga engaging counterparts (n = 57) (Pastucha et al., 2012). Findings from this report are limited by not knowing, however, whether other lifestyle choices affected outcomes in the group engaged in yoga.

In addition to traditional haematological risk factors, C-reactive protein (CRP) is an inflammatory marker associated with CVD (McDade et al., 2006) and psychological stress (Gouin, 2011). There is limited research investigating the effect *hatha* yoga intervention on CRP. A short RCT examined the effect of 60 minutes of yoga daily for four weeks on male railway drivers (n = 32) and the experimental group reported a reduction ($p < 0.05$) in highly sensitive (hs) CRP compared to the no-treatment control group (Shete et al., 2012). Supporting these findings, an 8-10 week RCT reported that 60 minutes two to three times per week of *hatha* yoga practice resulted in a reduction ($p = 0.016$) in hsCRP in heart failure patients compared to the usual-care control group (Pullen et al., 2010). In adults with hypertension, an RCT (n = 83) reported that two yoga interventions (60-minute supervised session and 30-minute daily home practice, or, 15-minute daily home practice) for 12 weeks did not improve hsCRP compared to a usual-care control group (Wolff et al., 2015). Adherence, which was not clearly reported, may have led to the limited benefits identified in this study. Unsurprisingly, similar findings were found in a healthier population, where controlled study reported no improvement in CRP in the experimental group after a 12-week *hatha* yoga intervention with 60 minute classes three times per week in premenopausal women (Cho et al., 2015). However, drop-out rate in this trial was 39% in the experimental group and 45% in the control group, which may have influenced findings (Cho et al., 2015). A descriptive review supports these equivocal findings, suggesting that in response to mind-body therapies, higher risk populations including those with CVD, depression or diabetes are more likely to see reductions in hsCRP (Bower & Irwin, 2016). It is also possible that null findings could have been affected by adherence to and/or dose of the intervention.

2.2.3 Effect of non-Bikram *hatha* yoga on adiposity

In certain populations, *hatha* yoga, particularly higher intensity styles, for example, heated styles or styles that emphasise continuous flow of postures, may elicit a metabolic response sufficient to induce improvements in body composition (Clay et al., 2005; Hagins et al., 2007; Pate & Buono, 2014). There is evidence to suggest that long term yoga practice can attenuate weight gain in middle-aged men and women (Kristal et al., 2005), and predicts lower body mass index (BMI) in women aged 45 years and older (Moliver et al., 2011) over a 10-year period. However, the most recent meta-analysis and systematic review reports that there is no effect of yoga compared to usual care on weight-related outcomes, except for a reduction of BMI in overweight-obese cohorts (Lauche et al., 2016). This recent review, however, included interventions that used any combination of yoga postures, breath control, meditation and/or lifestyle advice. By contrast, an earlier narrative review reported that yoga may be an effective method to improve weight-related outcomes, however, this review included uncontrolled trials and interventions were also not limited to *hatha* yoga specifically (Rioux & Ritenbaugh, 2013). The narrative review also reported that longer intervention duration, increased frequency of practice, a yogic dietary component, residential component (face-to-face intervention delivery at a yoga centre), more comprehensive inclusion of yogic components (e.g. *pranayama*, *asana*, philosophy, chanting) and home practice component were all related to improved weight-related outcomes. Further, a second systematic review and meta-analysis reports that yoga intervention may significantly reduce waist circumference compared to control groups

(Cramer et al., 2014). A smaller review summarising five RCTs reports that *hatha* yoga may reduce body weight and improve body composition in the experimental groups compared to controls (Manchanda & Madan, 2014). Supporting these reports, a six month RCT with a large sample size (n = 170) reported significant improvements in body composition outcomes (via bioelectrical impedance) including a reduction in body fat percentage ($p < 0.0002$) an increase fat free mass ($p < 0.04$), and reduction BMI ($p < 0.04$) in patients with coronary artery disease after a *hatha* yoga intervention (35-40 minutes, five days per week) compared to non-yoga control groups (Pal et al., 2011). In adults with and without metabolic syndrome an RCT (n = 173) investigated the effect of 12 weeks of *hatha* yoga intervention (60 minutes weekly) and the experimental group decreased waist circumference compared to control ($p < 0.001$) (Lau et al., 2015). In post breast cancer treatment patients a third study reported reduced body fat percentage ($p < 0.001$) after three, 60-minute *hatha* yoga classes a week for six months compared to two control groups prescribed the same frequency and duration of exercise (either an aerobic/ resistance/flexibility program or a self-selected program) (Hughes et al., 2015). This trial failed to use intention-to-treat analysis, potentially leading to an overestimation of adaptations in practice. The mechanisms for reduced adiposity in response to *hatha* yoga are unclear (Ross et al., 2016), however may include increased energy expenditure and reduced stress, via both increasing physical activity and emotional regulation (Lauche et al,, 2016). There is evidence suggesting both that obesity causes stress, and stress causes obesity (Foss & Dyrstad, 2011; Kyrou & Tsigos, 2009). *Hatha* yoga may target stress pathways, including the HPA axis, reducing the effect stress has on body composition.

2.2.4 Effect of non-Bikram *hatha* yoga on perceived stress

Acute studies and controlled trials varying in duration from three days to four months have reported decreased perceived stress as a result of participation in *hatha* yoga (Chong et al., 2011; Granath et al., 2006; Huang et al., 2013; Michalsen et al., 2005; Satyapriya et al., 2009). A systematic review reports that *hatha* yoga can reduce perceived stress, and that the *hatha* yoga may be as effective as other stress-reducing techniques, such as cognitive behavioural therapy and relaxation techniques (Chong et al., 2011). In stressed office workers an RCT (n = 239) compared a 12-week (60 minutes per week) *hatha* yoga treatment to a 12-week (14 hour) mindfulness treatment and to a no-treatment control group (Wolever et al., 2012). Both the *hatha* yoga and mindfulness intervention significantly reduced perceived stress ($p < 0.001$) compared to no treatment, with no significant differences identified between the two interventions. Further, an RCT (n = 50) revealed that *hatha* yoga reduced perceived stress in adults suffering from post-traumatic stress disorder (PTSD) after one 90-minute class a week for eight weeks compared to a no-treatment control group (Jindani et al., 2015). Large drop out in the experimental group, however, may have affected the between group findings, as an intention-to-treat model was not applied. In pregnant women, an RCT (n = 90) investigating the effect of a 16 weeks of daily *hatha* yoga for 60 minutes compared to a usual-care control group in pregnant women found that the experimental group significantly reduced perceived stress ($p < 0.001$) compared to the control group, which increased perceived stress by 6.6%. In contrast, an 8-week RCT (n = 52) investigated the effect of 60-minute *hatha* yoga sessions twice a week on perceived stress, mood and HRV in healthy women compared to a no-treatment control group and found no significant adaptation of perceived stress (Chu et al., 2015). Lack of positive findings in response to *hatha* yoga in this study could have been a result of the low-risk, stress-free cohort.

The added value of *hatha* yoga as a stress-management technique compared to techniques such as relaxation or mindfulness training, is the physical activity component inherent in *hatha* yoga practice. An intervention combining both meditation and movement components may be more effective in tackling the multifaceted nature of chronic disease in a stressed and sedentary population, however, the exact mechanisms for reducing stress via *hatha* yoga are not yet well-established (Riley & Park, 2015).

2.2.5 Effect of non-Bikram *hatha* yoga on self-efficacy

Self-efficacy can be defined as 'one's belief in his/her abilities to overcome barriers to achieve goals of importance'. Higher levels of self-efficacy have been shown to improve exercise uptake and adherence, while lower levels of self-efficacy can act as a barrier to exercise participation (Jerome & McAuley, 2012; Sherwood & Jeffery, 2000). Low self-efficacy is also associated with higher perceived stress (Yu et al., 2015). Specific domains of self-efficacy have been reported to improve in response to *hatha* yoga intervention. A 10-week RCT (n = 27) investigating the effect of *hatha* yoga for 60 minutes twice a week on sedentary adults reported a significant improvement in exercise self-efficacy ($p = 0.01$) by week five of the trial in those receiving yoga as compared to those in a no-treatment control group (Bryan et al., 2012). In another trial of pregnant women (n = 88), a significant increase in childbirth self-efficacy ($p < 0.001$) and significant reduction in discomfort at weeks 38-40 of pregnancy were noted in the experimental group, which engaged in a home-based, *hatha* yoga DVD intervention (30 minutes, three times per week, 12-14 weeks), as compared to the control group who did not engage in yoga (Sun et al., 2010).

Self-efficacy may also mediate the effect of *hatha* yoga on health. For example, a study specifically examining mediators of yoga for chronic low back pain reported that self-efficacy explained 36% (strongest mediator) of the effect of a 12-week *hatha* yoga intervention on reducing back-related dysfunction (Sherman et al., 2013). Further, a cross-sectional examination of university students (n = 4439) revealed that stress-management self-efficacy mediated the effect of stress on depression, particularly when students believed stress negatively influenced their academic performance (Sawatzky et al., 2012). In contrast to these findings, an RCT (n = 38) examined the effect of 12 weeks of *hatha* yoga for 75 minutes once per week, or six weeks of *hatha* yoga for 75 minutes twice per week, with a no-treatment control group in participants with PTSD (Martin et al., 2015). No between group changes in exercise self-efficacy were found (Martin et al., 2015). Authors suggested that despite lack of significant findings for exercise self-efficacy in this cohort, a decrease in external motivation in the experimental group may have been the start of a shift from exercising for external reasons towards exercising for internal reasons. Self-efficacy may underpin mechanisms for adaptation of certain psychological outcomes as well as encourage adherence to intervention and uptake of regular exercise.

2.2.6 Effect of non-Bikram *hatha* yoga on quality of life

Hatha yoga has been reported to have a positive effect on domains of quality of life (QoL) in various populations (Jorge et al., 2016; Lakkireddy et al., 2013; Lau et al., 2015; Tekur et al., 2010). A 12-week RCT examining the effect of a 75-minute *hatha* yoga session twice per week in post-menopausal women reported a significant improvement in global QoL ($p < 0.05$) compared to a no-treatment control group (Jorge et al., 2016). Further, reductions in symptoms of stress and depression were reduced in the yoga group. These changes to psychological health met or exceeded the changes reported in a third stretching intervention group. However, results must be interpreted with caution as an intention-to-treat analysis was not undertaken. In a group of adults with and without metabolic syndrome (n = 173), a 12-week controlled trial, consisting of weekly 60-minute *hatha* yoga classes, reported a significant improvement in health-related QoL (HRQoL; RAND 36-Item Health Survey, SF-36) in the general health domain ($p < 0.01$), the social functioning domain ($p < 0.01$), and the physical component score ($p < 0.01$) in the experimental group compared to a no-treatment control group (Lau et al., 2015). In a group of atrial fibrillation patients, a 12-week crossover trial examining the effect of one weekly 60 minute *hatha* yoga class on QoL in reported significantly improved several domains of HRQoL (SF-36) including physical functioning ($p = 0.017$), general health ($p < 0.001$), energy/fatigue ($p < 0.001$), social functioning ($p = 0.019$), and mental health ($p < 0.001$) (Lakkireddy et al., 2013). This trial may have been limited by the participants serving as their own control. In a shorter, intensive residential 7-day RCT (n = 80) examining the effect of *hatha* yoga on QoL (World Health Organisation QoL questionnaire) in participants with chronic low back pain (CLBP) the yoga group reported significant improvements to physical health, psychological health, social relationships and environmental health domains of QoL (all ($p < 0.01$) compared to a group receiving physical therapy (Tekur et al., 2010). This trial is limited by the short duration of the intervention, despite the intensive daily schedule of the intervention.

Changes to QoL after *hatha* yoga intervention are likely dependent on the cohort under investigation. In a *hatha* yoga RCT that delivered three 50-minute classes per week for 10 weeks on-site to office workers there were no changes to any domains of HRQoL (Cheema et al., 2013). The apparently healthy cohort of office workers, however, had higher levels of QoL compared to normative data.

2.3 Bikram yoga

Bikram yoga is a standardised system of *hatha* yoga developed by Bikram Choudhury (Choudhury, 2007). Choudhury was born in Calcutta in 1946 and worked in Bombay during the mid 1960’s using *asanas* to treat individuals for various ailments including heart disease, diabetes, arthritis, neurological diseases and back pain (Choudhury, 2007). Choudhury went on to develop a series of beginner level yoga *asanas* and breathing exercises for group-based practice that he believed would remedy many medical conditions (Choudhury, 2007). In 1973 Choudhury opened the first Bikram yoga school in the United States in California (Choudhury, 2007). Today, there are studios worldwide offering Bikram yoga classes (Bikram Yoga, 2012).

There are three main components that in combination characterise Bikram yoga: (1) the specific series of *asanas*, (2) the heated environment, and (3) the instructional dialogue. Each class is 90 minutes and involves the performance of 26 *asanas* and two breathing exercises (Appendix 1) within a heated room (40.6°C and 40% humidity). The sequence never changes, and the class is taught using a learned dialogue to specifically guide and align students into and out of postures. The first 45-50 minutes of class starts with a standing deep breathing exercise (*pranayama*) followed by standing *asanas*, which is then followed by a 2-minute *savasana* (relax lying supine, corpse pose) and 40-45 minutes of floor-based *asanas*. A 20-second *savasana* is taken between each *asana* in the floor series. Class finishes with a seated *kapalbhati* breathing exercise (quick, strong exhalations) and final *savasana*. For more detailed explanations of the individual *asanas*, please see descriptions by Choudhury in his text (Choudhury, 2007). All *asanas* in the series are considered beginner's *asanas.* None of the *asanas* in the series are considered inversions (e.g., headstand), nor do they require levels of flexibility and strength beyond normal ranges (e.g., seated lotus or crow pose). No previous yoga experience is required to attempt the class. The heated environment is said to help warm and prepare the body for movement, and assist with removing impurities from the body (Choudhury, 2007).

Several studies have investigated the health-related benefits of Bikram yoga training (Abel et al., 2012; Hart & Tracy, 2008; Hewett et al., 2011; Hunter et al., 2013; Hunter et al., 2013; Kudesia & Bianchi, 2012; Mukherjee et al., 2010; Pate & Buono, 2014; Sangiorgio et al., 2014; Tracy & Hart, 2013). These studies have never been comprehensively and critically reviewed. Therefore, the purpose of chapter three of this thesis is to summarise and contextualise studies that have investigated the health-related benefits of Bikram yoga, and propose recommendations for future research directions. This review has been published, as presented in chapter three, in *Evidence-Based Complementary and Alternative Medicine* (Hewett et al., 2015). However, to the author's knowledge, five studies recently published across seven papers (Baird et al., 2016; Hopkins et al., 2016; Hunter et al., 2017; Hunter et al., 2016; Medina et al., 2015; Rissell et al., 2014; Szabo et al., 2016) are not included in chapter three. A supplementary review of these studies is provided here.

2.3.1 Supplementary review of Bikram yoga studies

The most recent Bikram yoga research includes controlled and uncontrolled investigations into psychological health and vascular health. An RCT investigating the effect of an 8-week Bikram yoga intervention (two or more classes per week) on salivary cortisol, distress tolerance and affective eating in a stressed population of female restrained, emotional eaters (n = 27) compared to a no-treatment control group (n = 25) was reported across three publications (Baird et al., 2016; Hopkins et al., 2016; Medina et al., 2015). Mean weekly attendance was 1.56 ± 0.82 and 27% of experimental group participants met the minimum weekly attendance requirements. High cortisol reactors to stress in the experimental group decreased cortisol reactivity ($p = 0.042$) and had lower reactivity levels post intervention ($p = 0.013$) compared to the control group, whereas low reactors reported no changes (Hopkins et al., 2016). The experimental group also reported improved distress tolerance ($p = 0.046$), reduced binge eating frequency ($p = 0.001$) and reduced emotional eating ($p = 0.013$) compared to control (Medina et al., 2015). When examining adherence in the experimental group (n = 27), women with body image concerns reported higher adherence when distress tolerance was higher, however this was only true for overweight women (48% of sample, $p = 0.009$) (Baird et al., 2016). Their obese counterparts (33.3% of sample) reported a negative relationship between tolerance to distress and adherence ($p = 0.007$). This trial is the first to examine a physiological marker of stress and reveal that Bikram yoga may reduce physiological stress in higher risk adults. The evidence suggests that the Bikram yoga may improve distress tolerance, and may modify subsequent harmful coping techniques like overeating. However, despite positive findings, the study presents some limitations. Primarily, the self-report psychological measures may have been influenced by expectation-driven responses from participants in the yoga group. Without an active control group it is hard to attribute self-report findings to the intervention (Boot et al., 2013). Secondly, there is no mention of whether data collectors were blinded to group allocations. Lastly, there is no mention of whether engagement in non-intervention exercise or mind-body activities remained constant throughout the trial.

An uncontrolled trial investigated the effect of 60 consecutive days of Bikram yoga on core self-evaluation (CSE) and life satisfaction in 35 apparently healthy adults who were experienced Bikram yoga students (Rissell et al., 2014). Attrition rate was 37%, therefore 22 participants were included in data analysis. Males were more likely than women to drop out ($p < 0.001$). Participants reported increased CSE ($p = 0.011$) and life satisfaction ($p = 0.005$) after completing ≥ 48 classes in 60 days. This study presents major limitations, particularly with regard to study design. Primarily no control group was used, greatly increasing the potential for expectation-driven improvements in questionnaire responses (Boot et al., 2013). This may be particularly true considering that the cohort was experienced in Bikram yoga, and previous positive experiences with the intervention may further prime responses on self-report measures. Secondly, physical activity levels outside of the intervention were not recorded. Investigation of effectiveness using robust intention-to-treat RCTs in participants new to Bikram yoga or with poorer psychological health may reveal further insight into the effect of Bikram yoga on CSE and life satisfaction.

Health-related QoL (SF-36) was also assessed in an uncontrolled 8-week trial investigating the effect of three Bikram yoga classes a week on arterial stiffening in apparently healthy adults with BMI classified as normal or overweight/obese (n = 43) (Hunter et al., 2016). Baseline age, BMI, body fat and blood pressure were all significantly higher, and arterial stiffness was near significantly higher in the overweight/obese group. Both groups reported improvements in the emotional well-being domain of HRQoL ($p < 0.05$), and the general health domain improved ($p < 0.05$) in the normal BMI group only. Endothelial function, measured via brachial-ankle pulse wave velocity analysis, improved in the overweight/obese group only ($p < 0.05$). Attrition rate was 35%, and adherence to the weekly classes required was not reported. The authors speculated that changes in the overweight/obese group could be in response to both the stretching and heated environment present in Bikram yoga. Baseline arterial stiffness in the overweight/obese group tended to be higher ($p = 0.077$), and authors stated that the higher baseline values may have led to greater adaptation in the overweight/obese group. The major limitation to this study is the non-RCT design (i.e. lack of control group), which affects the psychological measure in particular by increasing the likelihood of expectation-driven responses to self-report findings (Boot et al., 2013). Further, participants were asked not to change their diet or exercise during the trial, however, this data was not reported.

The same authors investigated the effect of eight weeks of Bikram yoga, three times per week, on endothelial function in apparently healthy young (18-39 years) and older (40-79 years) adults (n = 36) (Hunter et al., 2017). At baseline, no differences in endothelial function were noted between groups. Endothelial function, assessed via flow-mediated dilation (FMD) at the brachial artery, improved in the older group only ($p < 0.05$). FMD decreased slightly in the younger group. This finding suggests that Bikram yoga may be a suitable adjunct therapy to reduce CVD risk for older adults who cannot or wish not to engage in traditional aerobic exercise, however, further robust research would be required to further explore the suitability of Bikram yoga in older adults. Authors suggest that lack of positive findings in the young group could be due to healthy baseline values of brachial artery FMD with little room for improvement. No significant changes were reported in BMI and body composition in either group, however trends ($p = 0.09$) towards reductions in body weight and BMI were noted in the older group. Attrition rate for the trial was 23% and no adverse events occurred. Despite positive findings, a major limitation to this study is the non-RCT design. Secondly, sample size was small, and there is no mention of whether data collectors were blinded to group allocation. Lastly, although participants were asked not to change their diet or exercise during the trial, this data was not reported.

Lastly, the acute effect of a Bikram yoga session on positive and negative affectivity and state-anxiety, and the relationship of these outcomes with perceived stress, was examined in 53 apparently healthy adults (Szabo et al., 2016). Outcomes were measured before and after the 90-minute class. Positive affect increased ($p = 0.037$), and negative affect ($p = 0.001$) and state-anxiety ($p < 0.001$) decreased after the class, regardless of perceived effort during the class. Reduced perceived stress was significantly correlated with reductions in negative affect and state-anxiety, and changes over time in all three outcomes were greater in participants with higher perceived stress compared to those with lower perceived stress. These findings suggest that physical exertion is not required for psychological benefit from Bikram yoga. Further research is required to determine which components of Bikram yoga (e.g. the heat, the instructional dialogue) influence acute psychological adaptation from Bikram yoga intervention. The main limitation this study, which was also noted by the authors, is the potential for a placebo intervention effect, which could not be accounted for due to the lack of an active control group (Boot et al., 2013).

In summary, the evidence from these five studies suggests that Bikram yoga may improve psychological health, reduce cortisol reactivity, and may improve vascular health in older and in overweight/obese adults. Further research should be carried out via intention-to-treat RCTs to corroborate these findings as well as address the major limitations pervasive throughout these studies. Future investigation into psychological health outcomes should take appropriate measures to reduce the potential placebo effect of Bikram yoga intervention. Lastly, investigations in unhealthy populations will enhance our understanding of the effects of Bikram yoga on psychological and vascular health.

2.4 The heated environment in Bikram yoga

The heated environment (40.6°C and 40% humidity) is a cornerstone feature of Bikram yoga and may aid in its effectiveness in abating CVD risk factors. Preliminary evidence suggests that Bikram yoga may elicit improvements in vascular function in older (40-79 years) adults and obese adults compared to younger adults and normal weight adults (Hunter et al., 2017; Hunter et al., 2016). By contrast, an earlier study from the same authors reported that a longer intervention (12 weeks) of unheated *hatha* yoga elicited no positive adaptation in measures of vascular function (Hunter et al., 2013). Hunter et al (2017) speculate that the heated environment was the most significant difference between the two investigations and it may, therefore, contribute to the subsequent varying results. In adults with increased CVD risk heat therapy alone has been shown to improve endothelial function (Imamura et al., 2001).

2.4.1 Sweat therapy

Sweat therapy has been used for many years across many cultures to promote psychological well-being (Eason et al., 2009). Studies have shown that sweat practices can induce relaxation, and have a positive effect on hyperactivity, mood and stress (Colmant & Merta, 2000; Eason et al., 2009; Masuda et al., 2005). Although Bikram yoga cannot be directly compared to sweat therapy practices, all the components can be observed in the traditional setting for Bikram yoga practice.

Eason et al (2009) proposed the Sweat Therapy Theoretical Model, which is comprised of five components that contribute to well-being: ‘cultural priming’, ‘exercise’, ‘self-regulation’, ‘metaphorical contextual elements’ and ‘interpersonal factors’ (Eason et al., 2009). ‘Cultural priming’ is the acceptance and perceived effectiveness of sweating practices as a result of its history of use in various cultures. Eason et al (2009) propose that sweat therapy may increase SNS activity similar to exercise, inducing similar physiological and psychological benefits, hence the ‘exercise’ component of the theory. ‘Self-regulation’ refers to the ability to regulate emotions and perceived stress with the rising ambient temperature in a sweat therapy session. ‘Metaphorical contextual elements’ refer to, for example, the symbolism of the heat and of sweating, which can be perceived as a cleansing or detoxifying agent. Lastly, ‘interpersonal factors’ refers to the closeness and communal importance of a group setting for sweat therapy. The concept of Bikram yoga as a sweat or heat therapy modality has not yet been explored formally, however, research in this area could reveal more about the psychological, social and emotional effects of Bikram yoga practice.

2.4.2 Sauna bathing

Prospective data indicates that more frequent sauna bathing is associated with reduced risk of sudden cardiac death, coronary heart disease, and all-cause mortality in Finnish males aged between 42 – 60 years (Laukkanen et al., 2015). Further, two weeks of sauna therapy (15 minutes per day) improved endothelial function in patients with CVD risk factors (Biro et al., 2003; Imamura et al., 2001). Preliminary evidence also suggests that thermal exposure (sauna bathing and spa treatment) may lead to increased resting heart rate variability in healthy subjects and athletes (Corsini et al., 2015; Stanley et al., 2015). Studies have reported that passive heat therapy can induce some of the same acute physiological responses as exercise (e.g. increased SNS activity), which may be a beneficial supplement to regular exercise, particularly in cohorts that are unable to engage in minimum physical activity requirements (Eason et al., 2009; Iguchi et al., 2012). *Hatha* yoga typically does not meet minimum metabolic requirements for minimum exercise recommendations when compared to traditional aerobic exercise, however, preliminary evidence suggests that Bikram yoga may have a higher energy expenditure than other forms of yoga (Fritz et al., 2013; Hagins et al,, 2007; Pate & Buono, 2014; Ray et al., 2011). The mechanism for potentially higher energy expenditure in Bikram yoga compared to other forms of *hatha* yoga is unknown. The added heat component of Bikram yoga may contribute to the higher energy expenditure, and the heated Bikram yoga environment may thus be an effective adjunct intervention for reducing CVD risk.

2.5 Introduction to heart rate variability

Heart rate variability (HRV) variables describe the autonomic influence of the sinoatrial node on beat-to-beat heart rate, revealing insight into the bidirectional relationship between the brain and heart when exposed to psychosocial stressors (Thayer et al., 2012).

The heart is innervated by the vagus nerve, which influences the heart parasympathetically. During perceived stress, parasympathetic tone decreases and sympathetic activity increases preparing the body for fight or flight (i.e., increased heart rate, increased blood cortisol and glucose, redistributed blood flow). Prolonged stress can therefore lead to problematic physiological adaptations that increase CVD risk (Rozanski et al., 2005). The Neurovisceral Integration Model suggests that perceptions of threat or safety (perceived stress), modulated by the amygdala and prefrontal cortex, can be reflected in HRV (Thayer et al., 2012). Further, a primary component of the model states that HRV is primarily influenced by activity in the brain rather than the heart. Reduced HRV is independently associated with an increased risk of disease and mortality (Nolan et al., 1998; Ryan et al., 2011; Thayer & Lane, 2007, 2009).

There are several variables within HRV that are used in research and each one reflects a slightly different component of HRV (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). Variables belong to either the time or the frequency domain. Variables in the time domain are all closely related and are calculated from r-wave to r-wave (RR) intervals. Time domain variables include standard deviation of all normal-to-normal (NN) intervals (SDNN), root mean square of successive differences between adjacent NN intervals (RMSSD), the proportion of the number of pairs of successive NN intervals that differ by 50ms divided by the total NN intervals (pNN50) and HRV triangular index. SDNN and HRV triangular index are both estimates of overall HRV. Frequency domains include very low, low, and high frequency (VLF, LF, HF) components. These measures reflect power in their respective frequency ranges. The HF component is reflective of vagal activity whereas the LF component of HRV reflects components of sympathetic as well as parasympathetic nervous system activity. The LF to HF ratio (LF:HF) is thought to reflect sympathovagal balance.

2.6 Relationship between HRV and mortality

A review of evidence presents a strong case for the relationship between HRV and CVD risk factors, and therefore, disease and mortality (Thayer et al., 2010). In an epidemiological study of 736 older adults from the Framingham Heart Study, an age, sex and clinical risk factors adjusted analysis reported HRV (LF, VLF, HF, total power) to be a significant predictor of all-cause mortality (hazard ratios 1.7 with 95% CI 1.37 to 2.09, 1.51 with 95% CI 1.27 to 1.79, 1.43 with 95% CI 1.15 to 1.79 and 1.6 with 95% CI 1.30 to 1.96, respectively, $p < 0.001$, $p < 0.001$, $p = 0.014$, $p < 0.001$ respectively) (Tsuji et al., 1996). A one standard deviation decrease in the LF component of HRV was associated with a 1.7 times greater hazard (95% CI 1.37-2.09) for all-cause mortality (Tsuji et al., 1996). Measuring HRV is minimally invasive and is inversely related to stress independent of confounding factors (Dishman et al., 2000).

2.7 HRV and CVD risk factors

Low HRV has been linked to several CVD risk factors including elevated CRP, metabolic syndrome markers, augmentation index (AIx) and reduced cardiorespiratory fitness (Buchheit & Gindre, 2006; Jaiswal et al., 2013; Kimura et al., 2006; Lanza et al., 2006; Poliakova et al., 2012; Rothberg et al., 2016). Several of these outcomes have also been linked to perceived stress, which may shed light on the role of stress in the development of chronic diseases (Foss & Dyrstad, 2011; Hamer et al., 2008; Pullen et al., 2010). Repeated activation of the HPA axis, which occurs during physiological stress, leads to chronic exposure to cortisol, which is associated with obesity, hypertension, dyslipidaemia and insulin resistance (Foss & Dyrstad, 2011; Rosmond, 2005).

2.7.1 HRV and haemodynamic CVD risk factors

A review of epidemiological studies reports that higher blood pressure is associated with reduce HRV when controlling for other potential mediators of HRV such as age, ethnicity, smoking status and BMI (Thayer et al., 2010). The review speculates that reduced HRV (vagal tone) may precede the development of hypertension, which is a well-known modifiable risk factor for CVD. Elevated systolic and diastolic blood pressure have also been correlated with reduced HRV in post-menopausal women (Kimura et al., 2006).

Hypertension and increasing age contribute to stiffening of the arterial walls. Although not a traditional risk factor, arterial stiffness can increase cardiovascular load and increase CVD risk (Romney & Lewanczuk, 2001; Vlachopoulos et al., 2010; Weber et al., 2004). Arterial stiffness is increased more in individuals with higher baseline CVD risk, for example sedentary adults (McGavock et al., 2006). There is limited research on the relationship between arterial stiffness and HRV, however one cross-sectional study in diabetic youths reported a significant inverse correlation between these two measures after controlling confounding variables (Jaiswal et al., 2013).

2.7.2 HRV and haematological CVD risk factors

Hyperlipidaemia measures, including total cholesterol, LDL cholesterol and triglycerides are reportedly higher (all $p < 0.05$) in postmenopausal women with reduced HRV (total power) compared to those with higher HRV (Kimura et al., 2006). In HIV patients undergoing antiretroviral therapy, reductions in time parameters of HRV including RMSSD and pNN50 are correlated with higher total cholesterol ($p = 0.011$; $p = 0.021$) and LDL cholesterol ($p = 0.012$; $p = 0.017$) (Askgaard et al., 2011). Higher 24-hour HRV, including SDNN and the HF component of HRV, has been correlated (both $p < 0.05$) with lower fasting blood glucose in men with CVD risk factors (Poliakova et al., 2012). Further, higher blood glucose levels in diabetics have been associated with lower HF component of HRV ($p = 0.01$) and total power ($p = 0.02$) and higher LF:HF ($p < 0.01$) (Rothberg et al., 2016). In healthy, young adults, however, there is recent evidence suggesting that higher fasting blood glucose within healthy ranges is associated with higher values of the HF component of HRV ($p = 0.031$), and lower values of the LF component of HRV ($p = 0.025$) and LF:HF ($p = 0.035$) (Lutfi & Elhakeem, 2016).

Although not a traditional risk factor, CRP is a non-specific marker of inflammation and has been linked to adiposity, a sedentary lifestyle, perceived stress and an increased risk of CVD (Esteghamati et al., 2012; Lin et al., 2010; McDade et al., 2006; Ridker et al., 2000). A cross-sectional study reported that increased perceived stress was associated with increased CRP (McDade et al., 2006). Although correlations have been demonstrated between all indices of HRV, several studies have reported that ultra and very low frequency (ULF, VLF) HRV, rather than HF HRV have the strongest correlations with CRP (Haensel et al., 2008; Lampert et al., 2008; Lanza et al., 2006).

2.7.3 HRV and adiposity

Stress has been shown to cause obesity and there is evidence to suggest that obesity may cause stress (Foss & Dyrstad, 2011; Kyrou & Tsigos, 2009). Markers of adiposity (i.e. waist circumference and BMI) are inversely correlated with the HF component of HRV in middle-aged men (Andrew et al., 2013; Lampert et al., 2008). In postmenopausal women, higher body fat percentage ($p < 0.01$) and BMI ($p < 0.05$) were correlated with reduced HRV (total power) (Kimura et al., 2006). Higher body fat percentage ($p < 0.05$) and waist circumference ($p < 0.05$) were also associated with reduced HRV indices in a study of obese men (Poliakova et al., 2012). Further, HRV-SDNN was reported to be lower in sedentary, obese individuals compared with sedentary, normal weight individuals, indicating that higher body weight may be associated with lower HRV independent of activity levels (Dietrich et al., 2008).

2.8 HRV and psychological health

In addition to CVD risk factors, HRV is related to several measures of psychosocial stress. In a cross-sectional study of healthy adults, scores from the Perceived Stress Scale (PSS) were inversely correlated with HRV independent of confounding variables including cardiorespiratory fitness, trait anxiety, age, gender, heart rate and mean arterial blood pressure (Dishman et al., 2000). An observational study reported that participants with PTSD had lower resting HRV than both a non-PTSD traumatised and non-traumatised control groups (Hauschildt et al., 2011). Further, HRV remained low, but did not decrease more than the control groups when exposed to stressors, suggesting a possible dampened SNS response (Hauschildt et al., 2011). Similar findings were reported in depressed adults (Garcia et al., 2012). Lower HRV and reduced parasympathetic activity was observed in response to stressors in depressed men compared to control, however, there was no difference in response reported by depressed women compared to control. In heart failure patients, depression and HRQoL were significantly associated with reduced HRV, however, only HRQoL was independently associated with HRV (Kao et al., 2014). Adults with anxiety disorders, in particular panic disorder, have also exhibited reduced HRV at rest compared to healthy controls (Pittig et al., 2013).

2.9 Effect of aerobic exercise on HRV

Cardiorespiratory fitness is inversely correlated with cardiovascular disease risk and all-cause mortality (Kodama et al., 2009). Higher maximal oxygen uptake (VO_{2max}) is associated with higher HRV (Buchheit & Gindre, 2006). HRV is 19% higher in active, obese individuals compared to sedentary, obese individuals, suggesting that physical activity has an important contribution towards HRV independent of BMI (Dietrich et al., 2008). HRV can be influenced directly by physiological adaptations to exercise (Carter et al., 2003). During acute bouts of aerobic exercise vagal tone decreases, sympathetic activity increases, and haemodynamic changes occur to adapt to the increased demands of exercise. Heart rate and stroke volume both increase resulting in an increase in cardiac output. Although the acute adaptations to aerobic exercise demand increased sympathetic control, the chronic adaptation, aside from improved cardiorespiratory fitness, is increased vagal tone (Buchheit & Gindre, 2006), increased stroke volume, and decreased resting and submaximal heart rate (ACSM, 2010). Chronic adaptations are due to the increased strength of the cardiac muscle, which leads to more blood being ejected from the heart with each contraction of the left ventricle. The heart can pump more blood at rest with a reduced heart rate, therefore increasing parasympathetic tone at rest. A meta-analysis of longitudinal trials lasting at least four weeks has shown that aerobic exercise interventions improve the HF component of HRV (Sandercock et al., 2005), and a 6-year RCT reported that low to moderate intensity exercise improved submaximal cardiorespiratory fitness, which was related to improvements in autonomic function (Tuomainen et al., 2005).

2.10 Effect of meditation on HRV

There are mixed reports on the effect of meditation on HRV. Mindfulness meditation practice was shown to acutely increase HF-HRV both in participants who suffered tension and migraine headaches (n = 39) and those who did not (n = 41) after completing a stress-inducing task compared to a mindfulness meditation description control group (Azam et al., 2016). Mindfulness meditation is based around observing, being aware of, and being present in any given moment without attachment, judgement or reactivity (Kabat-Zinn, 1990).

Another style of meditation, Transcendental Meditation (TM), was used in a 16-week RCT to examine its effect on HRV in coronary heart disease patients (Paul-Labrador et al., 2006). The TM technique includes repeating a personal mantra. The intervention also included several face-to-face interactions including one-on-one instruction, and the meditation group reported near significant improvements in the HF component of HRV (p = 0.07) compared to the CVD risk education control group, as well as improvements in metabolic syndrome risk factors. A third mediation technique, Vipassana meditation, was used in a short uncontrolled 10-day trial in apparently healthy adults (n = 36) (Krygier et al., 2013). Vipassana meditation is an intensive 10-day meditation practice focusing on objective awareness of physical sensations in the body. Breath awareness is used as a tool to help focus and concentration. The HF component of HRV improved acutely, but not significantly, and baseline values did not significantly change over the course of the trial. Lack of significant longer-term effects may be attributed to the short duration of the trial. It is important to note that different styles of meditation may yield different physiological response. For example, physiological and self-report measures of heart rate and effort respectively, indicate that a simple breathing meditation intervention arouses the SNS less than more advanced techniques such as loving-kindness and observing-thoughts meditation (Lumma et al., 2015). Further, level of meditative experience would be expected to influence physiological response, including HRV response, to different meditation techniques. Although *hatha* yoga is not considered meditation, it ultimately trains and disciplines the mind through observation of the body and breath when practicing *asana*, serving as preparation for meditation (Hewitt, 1983; Iyengar, 1991).

2.11 Effect of non-Bikram *hatha* yoga on HRV

Meditating on the body and breath in *asana* is a characteristic of *hatha* yoga practice, and *hatha* yoga may have effects on health outcomes similar to the effects of exercise (Ross & Thomas, 2010). It is therefore reasonable to hypothesise that *hatha* yoga could positively influence HRV via psychological and/or physiological changes. *Hatha* yoga sessions can acutely induce significantly increased HRV and decreased perceived stress (Huang et al., 2013; Khattab et al., 2007; Melville et al., 2012). The HF component of HRV can be increased acutely by a reduced respiration rate, which likely contributed to these positive findings. *Hatha* yoga might have positive effects on autonomic function and stress reduction, therefore, HRV may be a suitable physiological measure to examine changes in vagal activity in relation to changes in perceived stress.

While there is some evidence for acute improvements in HRV in response to *hatha* yoga in apparently healthy adults, recent systematic reviews conclude that the evidence does not yet describe a definitive effect of long-term *hatha* yoga practice on measures of HRV, including the HF and LF components of HRV, LF:HF, total power, SDNN, and RMSSD (Posadzki et al., 2015; Tyagi & Cohen, 2016). Both reviews reported that poor and/or varying methodology, varying populations (i.e. healthy to diseased) and varying yoga interventions limited the scope of the reviews. In addition, a main limitation to the review are the varying and broad definitions of ‘yoga’ for the inclusion criteria. Neither review specifically analyses *hatha* yoga explicitly and only one review limited the investigation to RCTs (Posadzki et al., 2015).

In apparently healthy populations, the evidence for favourable adaptation of the HF component of HRV in response to yoga RCTs is inconclusive (Posadzki et al., 2015). Ten RCTs ranging from one session to 16 weeks (one to seven days per week, 15-90 minutes per day) were suitable for review and only half reported that yoga intervention either acutely or chronically improved HRV outcomes (Posadzki et al., 2015). Two of these RCTs reported favourable adaptation of the HF component of HRV (Melville et al., 2012; Satyapriya et al., 2009). Firstly, 15 minutes of chair yoga acutely increased the HF component of HRV ($p < 0.05$) in 20 healthy adults compared to a meditation control group (Melville et al., 2012). Secondly, four weeks of daily yoga for 60 minutes was compared to the same volume of standard care in 90 healthy pregnant women (Satyapriya et al., 2009). The HF component of HRV was higher and LF:HF was lower both during the relaxation period post-yoga and during the supine rest period post-standard care (both $p < 0.001$). However, only the yoga group reported significantly increased HF component of HRV and reduced LF component of HRV (both $p < 0.001$) at the completion of the trial compared to the standard care group. The yoga group also reduced perceived stress ($p = 0.001$). Based on these findings, authors suggest that *hatha* yoga may effectively address stress-related complications of pregnancy (Satyapriya et al., 2009). A third 12-week RCT published more recently examined the effect of *hatha* yoga on the LF and HF components of HRV in older men (n = 60) with increased pulse pressure (Patil et al., 2015). The intervention group completed 60-minute supervised yoga classes six days per week and the control group engaged in a walking and stretching program under the same frequency and time prescription. The intervention group significantly increased the HF and LF components of HRV and LF:HF (all $p < 0.001$) compared to the control group. The intervention group also significantly reduced systolic blood pressure ($p < 0.001$), pulse pressure ($p < 0.001$) and mean arterial pressure ($p < 0.001$) compared to the control group.

By contrast, there are several RCTs reporting no change to HRV in response to yoga interventions ranging from one day to 16 weeks (Posadzki et al., 2015). Three RCTs reported no adaptation of the HF component of HRV in response to yoga in apparently healthy adults and older adults, though the RCTs ranged widely in volume from daily 60 minute classes for seven days to 90 minutes twice per week for four months (Bowman et al., 1997; Markil et al., 2012; Santaella et al., 2011). Two randomised *hatha* yoga trials published more recently also found no effect of yoga on HRV (Chu et al., 2015 ; Lin et al., 2015). An RCT investigating the effect of eight weeks of *hatha* yoga for 60 minutes twice a week in apparently healthy women (n = 52) found no significant improvements to HRV variables compared to a no-treatment control group (Chu et al., 2015). Lack of positive findings are unsurprising due to the healthy population investigated. Further, an RCT in mental health professionals reported no significant improvements to frequency domains of HRV, and an unexpected increase in LF:HF in the yoga group compared to control after six and 12 weeks of weekly *hatha* yoga for 60 minutes (Lin et al., 2015).

Hatha yoga may not induce a cardiovascular and stress-reducing response high enough to improve HRV in lower risk cohorts. The lack of change in healthy cohorts may also be due to the low intervention volume in some trials. One study suggested that non-sedentary population and higher levels of HRQoL in the study population compared to normative data may have nullified potential effects of physical activity and stress-reduction on HRV (Cheema et al., 2013). It is possible that the application of RCT design is ill-fitted to yoga interventions due to the holistic nature of yoga practice and the varying styles and prescriptions of yoga used. Nonetheless, further robust RCTs using appropriate cohorts, sample sizes and yoga prescription are needed to better understand the effects of *hatha* yoga and on HRV.

2.12 HRV and Bikram yoga

The effect of Bikram yoga on the ANS has not yet been examined, however, in some cohorts, the practice may lead to chronic physiological adaptations similar to those gained from aerobic exercise due to the low-to-moderate intensity metabolic response to Bikram yoga (Pate & Buono, 2014). HRV has also been reported to be lower in adults with certain anxiety disorders compared to healthy adults (Pittig et al., 2013), and Bikram yoga has been reported to acutely reduce state-anxiety after one class (Szabo et al., 2016). Further research is required to investigate the influence of Bikram yoga on HRV.

2.13 Adherence to yoga interventions

Adherence to lifestyle interventions is likely influenced by numerous factors (Lo, 1998). Exercise enjoyment and satisfaction has been shown to decrease during times of high stress (Stetson et al., 1997). In addition to psychological stress, sedentary adults may exhibit various characteristics that pose as barriers to conventional exercise, including low self-efficacy, obesity, time constraints, and low stage of behaviour change (e.g. pre-contemplation) (Sherwood & Jeffery, 2000). Characteristics that act as barriers to conventional exercise may also affect participation in *hatha* yoga (Cheung et al., 2015; Dayananda et al., 2014). For example, 'family commitments and occupational commitments', were found to be significant barriers to yoga practice in a cohort of recent yoga instructor graduates (Dayananda et al., 2014). Another study in older women with osteoarthritis reported that 'health problems', 'pain' and 'being too busy' were the main barriers to the continuation of post-intervention *hatha* yoga practice (Cheung et al., 2015). Regardless of the mode, planned exercise occur during leisure time (i.e. not during work hours or hours spent caring for family or doing household chores), which means exercise competes for priority with other leisure-time activities (Iso-Ahola, 2013). Some sedentary adults may rationalise perceived barriers to exercise (e.g. takes too much time) to engage in other enjoyable, often sedentary, leisure-time activities, for example watching TV, further reducing engagement in exercise (Iso-Ahola, 2013).

Limited adherence data exist in the current Bikram yoga literature. Studies of Bikram yoga (eight weeks) have either not reported on adherence (Hewett et al., 2015; Hunter et al., 2013; Hunter et al., 2017; Hunter et al., 2016), or have reported that attendance varies, ranging from 60% (Hopkins et al., 2016; Medina et al., 2015) to 94% (Hart & Tracy, 2008; Tracy & Hart, 2013). However, none of these studies provided an *a priori* definition of how attendance was computed indicating a lack of consistency of how attendance is defined (Hewett et al., 2015; Hopkins et al., 2016; Medina et al., 2015). To our knowledge, only one study has reported on predictors of adherence to Bikram yoga. Baird et al (2016) reported that in women with body image concerns, higher tolerance to distress predicted higher adherence, however this was only true for overweight women ($p = 0.009$). Their obese counterparts reported a negative relationship between tolerance to distress and adherence ($p = 0.007$). Other Bikram yoga studies mention that dropouts were attributed to time commitment of the trial and lack of enjoyment of the intervention, however to date, factors that predict or act as barriers to adherence have not been investigated (Hunter et al., 2017; Hunter et al., 2016; Tracy & Hart, 2013).

2.14 Summary

Reducing CVD risk reduces mortality and morbidity, and reduces the economic burden of chronic disease. Both inactivity and psychological stress are contributing factors for CVD risk, and an intervention targeting both factors could be an effective way to reduce risk. *Hatha* yoga combines relaxation, breath awareness and physical activity into the same activity, and studies have found potential benefits to participation in *hatha* yoga, including reduced psychological stress, as well as improved CVD risk factors in certain populations. Bikram yoga is a standardised style of *hatha* yoga comprised of beginner-level *asanas*, which purports to improve physical, physiological and psychological health outcomes, however, the current body of research is limited in depth and quality.

Reduced HRV is a measure of physiological stress and it can be measured un-invasively. HRV has also been linked to several important stress-related outcomes and CVD risk factors. Evidence of Bikram and non-Bikram *hatha* yoga's effect on HRV and cardiovascular risk factors is still inconclusive, and partially limited by poor study design. To date, no trial has examined the effects of Bikram yoga on HRV, however, the higher intensity of Bikram yoga compared to some other styles of *hatha* yoga, as well as the reported reduction in perceived stress following Bikram yoga, may lead to chronic adaptation of HRV.

In addition to perceived stress, Bikram yoga interventions have shown evidence of improved quality of life, distress tolerance, mindfulness and emotional eating. Non-Bikram yoga interventions report to improve other psychological health outcomes, including self-efficacy, in a variety of cohorts including those at higher risk for psychological stress. Self-efficacy can enhance exercise uptake and adherence, and no study yet has investigated the effect of Bikram yoga on this measure.

Finally, adherence to Bikram yoga intervention ranges widely and detailed reports of adherence are lacking. Adherence to exercise intervention is imperative for the positive adaptation of health outcomes, and the same is likely true for *hatha* yoga interventions. Therefore, an investigation into the predictors of and barriers to Bikram yoga intervention is warranted.

Chapter 3

The Effects Of Bikram Yoga On Health: Critical Review And Clinical Trial Recommendations

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3.1 Abstract

Bikram yoga is a style of *hatha* yoga involving a standardised series of *asanas* performed to an instructional dialogue in a heated environment (40.6°C, 40% humidity). Several studies evaluating the effect of Bikram yoga on health-related outcomes have been published over the past decade. However, to date, there are no comprehensive reviews of this research and there remains a lack of large-scale, robustly-designed randomised controlled trials (RCT) of Bikram yoga training. The purpose of this review is to contextualise and summarise trials that have evaluated the effects of Bikram yoga on health, and to provide recommendations for future research. According to published literature, there is evidence reporting that Bikram yoga may improve lower body strength, lower and upper body range of motion, and balance, in healthy adults. Non-RCTs report that Bikram yoga may, in some populations, improve glucose tolerance, bone mineral density, blood lipid profile, arterial stiffness, mindfulness, and perceived stress. There is vast potential for further, improved research into the effects of Bikram yoga, particularly in unhealthy populations, to better understand intervention-related adaptations and their influence on the progression of chronic disease. Future research should adhere to CONSORT guidelines for better design and reporting to improve research quality in this field.

3.2 Introduction

Bikram yoga is a popular, standardised system of *hatha* yoga developed by Bikram Choudhury (Choudhury, 2007), and today, there are Bikram yoga studios worldwide (Bikram Yoga, 2012). Three factors together distinguish Bikram yoga from other forms of hatha yoga: (1) the set sequence of 26 *asanas* and two breathing exercises (Figure 3.1), (2) the heated environment (40.6°C, 40% humidity), and (3) the instructional dialogue. Every 90-min class begins with standing *pranayama* (deep breathing) followed by the standing *asanas* (45-50 minutes, Figure 3.1, a-l). The standing sequence is followed by a two minute *savasana* (supine relaxation, i.e. corpse pose, Figure 3.1, 1-m) and a sequence of floor *asanas* (35-40 minutes, Figure 3.1n-aa). A 20 second *savasana* is taken between each *asana* in the floor series. Class finishes with a seated *kapalbhati* breathing exercise (i.e. quick, strong exhalations) and a final *savasana*. Choudhury suggests that the heated environment helps warm and prepare the body for movement, and assists with removing impurities from the body (Choudhury, 2007).

Several studies have investigated the effects of Bikram yoga practice on health using various study designs (Abel et al., 2012; Hart & Tracy, 2008; Hewett et al., 2011; Hunter et al., 2013; Hunter et al., 2013; Kudesia & Bianchi, 2012; Sangiorgio et al., 2014; Tracy & Hart, 2013), however, to our knowledge, these studies have never been synthesised and critiqued and, accordingly, there is no consensus in the scientific literature regarding the effectiveness of Bikram yoga on health. Therefore, the purpose of this review is two-fold: (1) to summarise studies that have investigated the effect of Bikram yoga practice on health-related outcomes, and (2) to provide recommendations for the development of more robust trials and novel research questions to address the limitations of the existing literature.

Figure 3.1. Bikram yoga sequence of *asanas*

3.3 Review of the literature

Several studies have examined the chronic and acute effects of Bikram yoga practice in apparently healthy adults (Hart & Tracy, 2008; Hewett et al., 2011; Hunter et al., 2013; Hunter et al., 2013; Tracy & Hart, 2013), and obese adults (Hunter et al., 2013). Health-related outcome measures that have been assessed include measures of physical fitness, cardiovascular disease risk factors, psychological health, pulmonary function, sleep quality, bone density and metabolic cost. Only one trial reviewed used a randomised controlled trial (RCT) study design. A summary of these studies can be found in Table 3.1.

Table 3.1 Characteristics of Bikram trials reviewed

Study identification	Country	Sample size	Population: Major inclusion criteria	Population: Major exclusion criteria	Sex (M/F)	Mean age (years)	Treatments	Control conditions	Trial duration (weeks)	Outcome Measures	Main Findings
Randomised controlled trial											
Tracy & Hart, 2013; Hart & Tracy, 2008	USA	21	Apparently healthy, relatively sedentary (<2 hours/week purposeful exercise <moderate intensity - one active subject in the yoga group and one in the control group)	Medical condition or medication that could influence participation or dependent measures, yoga practice within 4 months prior to study	M/F	27	Bikram's beginner's yoga class (room heated to 40°C, 40% humidity , same 26 *asanas* and breathing exercises each class), 90-min/class, 3 classes/week. Average attendance 22.5 classes	No treatment	8	Physical strength (isometric deadlift, hand grip strength, MVC of knee extensors/elbow flexors, concentric/eccentric steadiness), functional fitness (sit-and-reach and shoulder flexibility, single-leg balance), cardiovascular fitness (VO2max, resting BP), body composition (fat mass and lean body mass using DXA)	increased isometric deadlift strength (p=0.04 between groups), increased knee extensor MVC within and between groups (p<0.05, p<0.01), increased balance yoga group (p<0.05) increased back/hamstring flexibility (p<0.001 between groups), trend towards significance for shoulder flexibility and for decreased fat mass in yoga group (p=0.069)
Controlled trials											
Hunter, Dhindsa, Cunningham, Tarumi, Alkatan, & Tanaka, 2013	USA	young=14 older=15	Sedentary (<2 days/week physical activity for past 6 months), lean participants BMI 18.5-24.9 and obese participants BMI>30	Smoking within last 6 months, uncontrolled diabetes, personal history of stroke, prior myocardial infarction, known coronary heart disease	M/F	young=32 older=46	Bikram's beginner's yoga class (room heated to 40°C, 40% humidity , same 26 *asanas* and breathing exercises each class), 90-min/class, 3 classes/week	No non-yoga control	8	Glucose tolerance (75g GTT, FPG) body composition (fat mass and lean body mass using DXA, BMI, body mass)	increased glucose tolerance in obese subjects (p<0.05), decreased body mass (p<0.05) and BMI (p<0.05) in obese subjects

Hunter, Dhindsa, Cunningham, Tarumi, Alkatan, Nualnim & Tanaka, 2013a	USA	young=24 older=18	Sedentary (no habitual activity over last 6 months), young participants aged 18-39, older participants aged 40-70	Pregnancy, uncontrolled hypertension, infection within last 4 weeks, renal disease, adrenal or endocrine tumours, prior myocardial infarction, known coronary heart disease, chronic heart failure, personal history of stroke or cardiac arrhythmias, diabetes, heat intolerance and cardiovascular or hormone replacement therapy medications	M/F	young=30 older=53	Bikram's beginner's yoga class (room heated to 40°C, 40% humidity, same 26 *asanas* and breathing exercises each class), 90-min/class, 3 classes/week	No non-yoga control	8	Arterial stiffness (carotid artery compliance, carotid pulse pressure), body composition (body mass, fat mass using DXA), blood glucose measures (HbA1c, FBG, plasma insulin, HOMA-IR), cardiovascular health (total, LDL and HDL cholesterol, triglycerides, BP), flexibility (sit-and-reach)	increased carotid artery compliance in young adults (p<0.05), decreased arterial stiffness in young adults (p<0.05), decreased plasma insulin and HOMA-IR in older group (p<0.01), decreased total and LDL cholesterol in older group (p<0.05, decreased total and HDL cholesterol in young group (p<0.05), increased flexibility both groups (p<0.01)
<u>Uncontrolled trials</u>											
Hewett, Ransdell, Gao, Petlichkoff, & Lucas, 2011	USA	51	NR	Bikram yoga practice at all in past 3 months and long-term within last 2 years, medical conditions that did not pass medical clearance for participation.	M/F	32	Bikram's beginner's yoga class (room heated to 40°C, 40% humidity, same 26 *asanas* and breathing exercises each class), 90-min/class, ≥ 3 classes/week. Average attendance 28.6 classes	No control	8	Psychological health (perceived stress, mindfulness), cardiovascular fitness (predicted VO2max, RHR), physical fitness (sit-and-reach and shoulder flexibility, single-leg balance)	increased mindfulness (p<0.01, d=0.89), perceived stress (p<0.01, d= -0.79), predicted VO2 (p<0.01, d=0.24), flexibility (p<0.01, d=0.63), balance (p<0.01, d=0.53), correlation between mindfulness and perceived stress (r= -0.43, p<0.01) and mindfulness and resting heart rate (r= -0.30, p<0.04)

Kudesia & Bianchi, 2012	USA	13	Apparently healthy, were planning to start or already practice Bikram yoga	Medical problems or medications that might interfere with sleep monitor's algorithm (e.g. epilepsy)	M/F	35	Bikram's beginner's yoga class (room heated to 40°C, 40% humidity, same 26 *asanas* and breathing exercises each class), 90-min/class, 2-12 classes/14 days	N/A	2	Sleep architecture (time spent in each sleep-wake stage, duration of awakenings)	decreased duration of awakenings on days of Bikram yoga practice (more rapid return to sleep after nocturnal awakenings)
<u>Longitudinal study</u>											
Sangiorgio, Mukherjee, Lau, Mukherjee, Mukhopadhyay & Ebramzadeh, 2014	USA	9	Female (30-59y), certified Bikram yoga instructors, practicing minimum 3 years, good physical health	NR	F	51 (at 5-year follow-up)	Continued practice of Bikram's beginner's yoga class (room heated to 40°C, 40% humidity, same 26 asanas and breathing exercises each class), 90-min/class, 3+ classes/week for 5 years. Continued teaching of Bikram yoga during 5-year period.	N/A	5 years	Bone mineral density (at spine, hip and whole body using DXA)	Premenopausal at follow up showed mean increased BMD at the femoral neck (6.6% ± 5.5%), total hip (2.0% ± 3.8%), lumbar spine (1% ± 4.7%). Postmenopausal at follow up showed mean decrease in BMD at the femoral neck (-6.0% ± 6.6%), total hip (-8.1% ± 6.1%) and lumbar spine (-5.6% ± 9.1%).
<u>Cross sectional & Acute studies</u>											
Pate & Buono, 2014	USA	26	Healthy adults (18-57y), current Bikram practitioners with varying levels of experience (<20 classes, >20 classes)	Positive responses on PAR-Q, pregnancy	M/F	33	N/A	N/A	N/A	Acute response to Bikram yoga session in temperature controlled chamber (40°C, 40% humidity) including metabolic (VO2), cardiovascular (HR) and sweat rate response	Average overall VO2 9.5ml/kg/min, average overall intensity 2.9METS, average overall EE/session 286kcal (179-478), higher relative EE for more experienced practitioners
Abel, Lloyd, Williams & Miller, 2012	USA	LE=17 HE=14	Apparently healthy adults	Signs or symptoms of heart, pulmonary or metabolic disease	M/F	LE=44 HE=38	N/A	N/A	N/A	Pulmonary function (FVC, FEV1, FVC/FEV1, PEFR, MVV), cardiovascular fitness (VO2max, RHR, BP)	Weak correlation of Bikram experience with FEV1 (r=0.37) and with % predicted FVC (r=0.38)

Fritz, Grossman, Mukherjee & Tracy, April 2013 (poster session at Rocky Mountain ACSM annual meeting)	USA	19	Current Bikram yoga practitioners attending ≥2 classes/week for at least 1 year	NR	M/F	30	N/A	N/A	N/A	Acute response to Bikram yoga session in temperature controlled chamber (40°C, 40% humidity) including metabolic (VO2), cardiovascular (HR), thermal (internal temperature) response and RPE	Average VO2 13ml/kg/min, average RPE 4.5, average HR 134 BPM, average overall intensity 3.7METs, overall EE 333-459kcal, elevated core temperature within safe range (max 101.6°F)

Abbreviations: BMI, body mass index; BP, blood pressure; BPM, beats per minute; CV, coefficient of variation; DXA, dual-energy x-ray absorptiometry; EE, energy expenditure; EEG, electroencephalogram; F, female; FEV1, forced expiratory volume in one second; FPG, fasting plasma glucose; FVC, forced vital capacity; GTT, glucose tolerance test; HbA1c, haemoglobin A1c; HE, high experience; HOMA-IR, homeostasis model of assessment of insulin resistance; HR, heart rate; LE, low experience; M, male; MRI, magnetic resonance imaging; MVC, maximal voluntary contraction; MVV, maximum voluntary ventilation; NR, not reported; PAR-Q, physical activity readiness questionnaire; PEFR, peak expiratory flow rate; RHR, resting heart rate; RPE, rate of perceived exertion; VO2, volume of oxygen uptake.

Physical Fitness

Physical fitness consists of five health-related domains (cardiovascular fitness, muscular endurance, muscular strength, flexibility, body composition) and six skill-related domains (balance, reaction time, speed, agility, power, coordination) (Hoeger & Hoeger, 2010). The health-related components of physical fitness are particularly interesting as they are associated with better health status and QoL, and lower risk of chronic diseases, disability and mortality (Center of Disease Control and Prevention, 2011; Chien et al., 2010; Leś & Gaworska, 2011).

Four studies to date have evaluated the effect of Bikram yoga training on measures of health- and/or skill-related physical fitness (Hart & Tracy, 2008; Hewett et al., 2011; Hunter et al., 2013; Hunter et al., 2013; Tracy & Hart, 2013). Hart and Tracy (Hart & Tracy, 2008; Tracy & Hart, 2013) examined the effects of an 8-week Bikram yoga intervention (three classes per week) on body composition, flexibility, muscular strength and steadiness (neuromuscular control), cardiorespiratory fitness (VO_{2max}), and balance in 21 apparently healthy adults. Thus far, this study is the only one to use an RCT design. Participants were randomised to a Bikram yoga group (n = 10) or control group (n = 11), and were instructed to maintain their current physical activity and dietary habits during the study. Upon completion of the 8-week intervention, the yoga group significantly increased lower-body range of motion assessed by the standard sit-and-reach test as compared to the control group ($p < 0.001$). The yoga group significantly improved balance, as assessed by a single-leg balance test ($p < 0.05$), and significantly improved isometric dead-lift strength ($p = 0.04$) compared to the control group. Isometric maximal voluntary contraction evaluated via a load cell device at the knee joint significantly increased in the yoga group compared to the control group ($p < 0.01$), which showed a 10% decrease ($p > 0.05$). No changes were identified in upper body strength, namely, isometric handgrip strength ($p = 0.30$) or elbow flexor strength and steadiness. In support of these findings, significant improvements in sit-and-reach scores within and/or between groups after three or more classes per week for eight weeks were reported in one uncontrolled trial (Hewett et al., 2011) and one controlled trial (Hunter et al., 2013) examining apparently healthy cohorts. Furthermore, the uncontrolled 8-week trial also reported significant improvements in single-leg balance ($p < 0.01$), as well as improved upper body range of motion as assessed by a total-body rotation test (Hewett et al., 2011).

Improvements in range of motion and balance are unsurprising given the nature of *hatha* yoga, and these results are supported by previous research (Lau et al., 2015; Tiedemann et al., 2013; Tran et al., 2001). The *asanas* that emphasise trunk and hamstring flexibility in a Bikram class are held for anywhere between 10-60 seconds (for specific *asanas* see Figure 3.1, e-h, o, x-z) allowing for improved passive and active range of motion (Roberts & Wilson, 1999). There is some evidence to suggest that locally applied moist heat increases active and passive range of motion of the muscles comparable to static stretching or an active warm up (Knight et al., 2001; Robertson et al., 2005). The heated environment in Bikram yoga (in addition to the physical activity of the yoga) may impose a similar effect on the tissues of the muscular system. The *asanas* that are performed on one leg for between 10-60 seconds (for specific *asanas* see Figure 3.1, c-f, k-l) would likely contribute to the improvement in single-leg balance. An emphasis on *asanas* involving lower body strength and frequent isometric contraction the quadriceps throughout the class (see Figure 3.1, c-g, i, l, s) likely explains improved lower body strength, and unchanged upper body strength (Tran et al., 2001). Future recommendations for assessing fitness outcomes include examining a cohort with musculoskeletal conditions that would benefit from improved muscular fitness and range of motion (e.g. cohorts with falls risk, low back pain). Although insignificant, greater changes in muscular steadiness were observed in participants with lower baseline values, supporting further investigation into the effects of Bikram yoga in sedentary individuals (Hart & Tracy, 2008). Additionally, improved single-leg balance in older adults after an Iyengar yoga intervention indicate that it may also be valuable to assess functional movement outcomes, for example, a 10-repetition maximum, or a Fallscreen assessment for falls risk (Lord et al., 2003; Tiedemann et al., 2013). Improvements in flexibility, strength and balance have a tremendous impact on QoL, especially in older adults, given that these aspects of physical fitness decline with age, are necessary for activities of daily living, and are associated with falls risk (Ehrman et al., 2013).

Body composition is a health-related component of fitness and excess adiposity is a cardiovascular disease risk (CVD) factor. To date, no Bikram yoga study has reported significant changes in adiposity or lean muscle mass when measured using dual-energy x-ray absorptiometry (DXA) (Hunter et al., 2013; Hunter et al., 2013; Tracy & Hart, 2013). Tracy and Hart (Tracy & Hart, 2013) reported a trend toward reduced body adiposity in the yoga group ($p = 0.069$), which, despite randomisation, had higher baseline adiposity (28.4 ± 6% vs. 20.8 ± 8.1%, $p = 0.03$). Two controlled trials also reported no significant changes in body composition within or between groups after an 8-week Bikram yoga program (three times per week), however, older, obese participations showed a significant decrease in BMI from 34.3 ± 4.7 to 33.7±4.9 ($p < 0.05$) (Hunter et al., 2013; Hunter et al., 2013). Though no significant changes have been observed to date, many factors contribute to alterations in body composition. Participants in these studies were asked not to change their current exercise and diet habits, however, energy intake and expenditure data during the trial was not collected. Therefore, it is difficult to ascertain whether or not external factors may have contributed to body composition measures at completion of the trial. Accounting for confounding factors and prescribing an effective intervention volume should be included in future RCT design examining the effects of Bikram yoga on body composition. Potential changes in body composition in certain populations (i.e. sedentary, unfit) after a Bikram yoga program could result from increased energy expenditure and/or increased muscle mass. Furthermore, intervention-related reductions in stress may improve regulation of hormones in the hypothalamic-pituitary-adrenal (HPA) axis, like cortisol, that are known to contribute to visceral adiposity (Kyrou & Tsigos, 2009; Rosmond, 2005). Previous research of other styles of *hatha* yoga reports acute and chronic intervention-related improvements to stress, inflammation, acute cortisol, leptin and adiponectin (Kiecolt-Glaser et al., 2010; Kiecolt-Glaser et al., 2012; Michalsen et al., 2005). Future Bikram yoga RCTs could examine additional markers including leptin, adiponectin, and cortisol to further investigate the effects of Bikram yoga on stress-related components of metabolism.

Despite the current lack of evidence for Bikram yoga as a tool to significantly improve body composition, acute data still lends valuable insight into the energy expenditure of, and potential, population-dependent (i.e. unfit, sedentary) body composition adaptations to, a Bikram yoga class. A cross sectional study of 24 apparently healthy adults of varying Bikram yoga experience used an environmental chamber and metabolic measurement cart (TrueOne, Parvomedics) to examine the acute physiological adaptations to a single Bikram session performed to a standardised audio recording of a class (Pate & Buono, 2014). The mean relative VO_2 for the whole session was 9.5 ± 1.9 $ml \cdot kg^{-1} \cdot min^{-1}$ and the intensity of the class was 2.9 METS, with postures ranging from light to moderate intensity (<3.0 to 3.0-6.0 METS) over the class. Absolute energy expenditure ranged from 179 to 478 kcals per session (mean 286 ± 72 kcals). The more experienced group (>20 classes experience) reported significantly higher relative energy expenditure, predicted maximal heart rate and sweat rate compared to the novice group (<20 classes experience). These findings are supported by similar trends in unpublished data presented at the 2013 Rocky Mountain ACSM Annual Meeting, however, the unpublished data reports higher values for energy expenditure and average intensity (333-459 kcals, 3.7 METS) over the whole class in experienced practitioners (>12 months experience, n=19). Based on this acute data, and although it appears that Bikram yoga elicits a greater average in-session MET level compared to other forms of *hatha* yoga (Clay et al., 2005; Hagins et al., 2007), the prescribed 8-week interventions in the studies reviewed may be insufficient for weight loss considering that ACSM recommends building up to 250-300 minutes of moderate intensity aerobic exercise per week for weight loss and maintenance of long term weight loss (ACSM, 2006). Discrepancies in oxygen consumption values between these two current reports examining may be due to the experience level of the sample and possibly the method of gas analysis, although the latter is purely speculation. The initial *pranayama* exercise is performed by inhaling through the nose, and exhaling through the mouth (Choudhury, 2007), which would be interrupted by wearing a nose clip. Breathing exercises aside, during most of the *asanas* in a *hatha* yoga class, the instruction is to breathe through the nose only (Hewitt, 1983; Iyengar, 1991), and although there is no definitive data to suggest that submaximal measurements of oxygen consumption are affected by the type of gas analysis system (i.e. face mask, or mouth tube and nose clip), it may be worth consideration in future oxygen consumption analysis of *hatha* yoga postures.

The only study examining aerobic capacity in a controlled manner reported no significant change in VO_{2max} over an 8-week period in apparently healthy adults (Balke treadmill test, TrueOne, Parvomedics). This may explain why the aerobic capacity of Bikram practitioners is not significantly different than that of the general population (Abel et al., 2012; Tracy & Hart, 2013). Research that has reported increased aerobic capacity after an 8-week Bikram yoga trial used a predictive VO_{2max} measure (1-mile walk), which is not as reliable as an actual VO_{2max} test. In-session VO_2 data shows that the average intensity of a Bikram yoga session is light to moderate (Pate & Buono, 2014), suggesting that the cardiovascular adaptation may be great enough to improve VO_{2max} in certain cohorts such as populations suffering from reduced cardiorespiratory fitness (e.g. sedentary individuals, asthmatics, older adults), which is significant, as reduced cardiorespiratory fitness is considered an independent risk factor for cardiovascular disease (Franklin & McCullough, 2009). Furthermore, intervention duration may have been too short to establish significant changes in cardiorespiratory fitness (ACSM, 2006).

Cardiovascular disease risk factors

The World Health Organisation reports that 38% of total deaths in the US are attributable to CVD and diabetes (World Health Organisation, 2011). Several controlled trials have investigated the effect of Bikram yoga training on various CVD risk factors. One controlled trial examined the effects of an 8-week Bikram yoga program (three classes per week) on arterial stiffness, measures of blood glucose regulation (HbA1c, fasting blood glucose, plasma insulin, and insulin resistance via homeostatic model assessment; i.e. HOMA-IR), blood lipids (total cholesterol, low density lipoprotein (LDL), high density lipoprotein (HDL), triglycerides), blood pressure and body composition in healthy young adults compared with older adults (Hunter et al., 2013). As mentioned previously, this trial did not report significant improvements in body composition. In the younger group, carotid artery compliance significantly increased ($p < 0.05$) and beta-stiffness significantly decreased ($p < 0.05$) compared to baseline. Longer interventions may not necessarily improve arterial stiffness in older adults, yet arterial stiffness is an independent risk factor for CVD (Vlachopoulos et al., 2010). Seeing as an appropriate prescription for Bikram yoga is still unclear, measuring arterial stiffness in this cohort using a longer Bikram yoga intervention with more frequent weekly sessions may be warranted even though there has been no observed change in this cohort to date (Hunter et al., 2013).

Further, HDL and total cholesterol decreased in young adults ($p < 0.05$) while LDL and total cholesterol decreased in older adults compared to baseline ($p < 0.05$). This finding in young adults is surprising considering that exercise generally contributes to HDL increases (Ginsberg, 2000). Fasting blood glucose and HbA1c did not change in either group, however plasma insulin and HOMA-IR both significantly decreased in older adults only when compared to baseline ($p < 0.01$). Further investigation is essential to discern the likely mechanisms responsible for metabolic profile changes. Potential reasons for the significant changes include the stress-reducing effects of yoga (Rosmond, 2005), the heated environment (Gupte et al., 2009), and unrecorded dietary changes. Scientific reviews report evidence of yoga improving diabetic symptoms and risk factors (including insulin sensitivity and glucose tolerance), however, more research is required to draw stronger conclusions (Innes & Vincent, 2007; Sharma & Knowlden, 2012).

Brachial blood pressure (systolic and diastolic) did not decrease significantly, which was also the case in a previous 8-week *hatha* yoga trial in normotensive adults (Hunter et al., 2013; Papp et al., 2013). Three additional studies have investigated the effect of Bikram yoga practice on resting heart rate and systolic and diastolic blood pressure (Abel et al., 2012; Hewett et al., 2011; Hunter et al., 2013; Tracy & Hart, 2013). All four studies to date have been conducted with normotensive participants and, as expected, all reported no significant change over time (Abel et al., 2012; Hewett et al., 2011; Hunter et al., 2013; Tracy & Hart, 2013). The cross-sectional study reported that compared to novice students, regular Bikram yoga practitioners had lower mean blood pressures and resting heart rates than national US averages. It is possible that chronic Bikram yoga practice may help to maintain healthy blood pressure values (Abel et al., 2012). The light to moderate aerobic intensity over a longer duration (i.e. > eight weeks), as well as more regular sessions (i.e. three to seven days per week) may be enough in deconditioned and hypertensive participants to affect blood pressure (ACSM, 2006; Cade et al., 2010; Pal et al., 2011). Another possible influence on blood pressure could is stress, and Bikram yoga has been shown to reduce perceived stress (Hewett et al., 2011).

A more recent study by the same research group examined the effects of an 8-week Bikram yoga program (three classes per week) on body composition, and glucose tolerance in young, lean (BMI= 22.1 ± 2.1kg/m^2, 28 ± 7% body fat) and older, obese (BMI = 34.3 ± 4.7kg/m^2, 44 ± 6% body fat) sedentary participants (Hunter et al., 2013). Glucose tolerance significantly improved in older, obese participants ($p < 0.05$) but, as expected, not in young, lean participants. Authors suggest that this is likely due to the increased insulin resistance that occurs in obese populations but not healthy populations. There were no significant changes in fasting plasma glucose over time in either group. In both controlled trials, participants were asked to continue with their normal diet and exercise routines, however this data was not collected (Hunter et al., 2013; Hunter et al., 2013). Changes in diet and exercise would certainly influence glucose management outcomes, and exercise and diet data should be reported in future trials.

Pulmonary Function

Pulmonary function can be reduced as a consequence of aging (Stanojevic et al., 2008) and chronic diseases, including asthma, emphysema, bronchitis, metabolic syndrome, and diabetes (Hesselbacher et al., 2011; Pelkonen et al., 2006; Weiss et al., 1992; Yeh et al., 2011). Reduced pulmonary function can have significant implications including reduced physical activity and associated chronic conditions including diabetes and CVD (Adams et al., 2006). Aerobic exercise, inspiratory muscle training, diaphragmatic breathing training and *hatha* yoga have been shown to improve pulmonary function outcomes in cohorts with reduced baseline values (Huang et al., 2011; Shaw et al., 2010; Spruit et al., 2004; Vempati et al., 2009), whereas, in apparently healthy adults, no changes are seen after a 12-week aerobic exercise program (Grisbrook et al., 2012).

A cross sectional study examining measures of pulmonary function in 31 apparently healthy Bikram yoga practitioners reported no significant difference between those of limited experience (0.07 ± 0.06 years) and those of more experience (4.16 ± 2.8 years) (Abel et al., 2012). There were no differences in height, weight or age between the groups. When classified by gender, aerobic capacity (VO_{2max}) of this cohort was classified as 'good' according to ACSM (ACSM, 2006). It is unsurprising that pulmonary function and aerobic capacity were not different based on level of experience when compared to population norms, seeing as reduced pulmonary function (e.g. forced expired volume in one second) is seen only in those with pulmonary dysfunction (ACSM, 2006). Furthermore, because pulmonary function varies according to gender, it would be useful to have results presented for females and males separately to better understand the data. There was a weak but significant relationship between Bikram yoga experience and percent predicted forced vital capacity ($r = 0.38$, $p < 0.05$), and forced expired volume in one second ($r = 0.37$, $p < 0.05$). These results could have been influenced by the final breathing exercise in a Bikram yoga class, which uses the abdominal muscles to repeatedly exhale the breath at a moderate pace (Choudhury, 2007). A review reports that in apparently healthy adults, changes in pulmonary function in response to *hatha* yoga are related to initial fitness level and duration of *pranayama* exercises (Abel et al., 2013), which perhaps indicates that a Bikram yoga class does not have enough specific *pranayama* exercises to elicit a significant improvement in pulmonary function in healthy individuals. Future Bikram yoga RCTs are warranted, and in order to investigate further, future RCTs should address confounding factors including ethnicity, gender, and smoking status, and should examine cohorts that have room to improve function, such as asthmatics or sedentary individuals.

Bone Mineral Density

Maintaining BMD throughout life is critical for health outcomes (osteoporosis, falls-related fractures) and QoL (Dennison et al., 2010; Dennison et al., 2006). In adults, the emphasis should be placed on non-pharmaceutical interventions such as nutrition, resistance training and impact based exercise, for example running, to minimise BMD loss and reduce the risk of fractures in later life. Given that Bikram yoga has been shown to significantly improve lower limb strength and single-leg balance it may reduce the risk of falls and fractures, similar to other *hatha* yoga interventions (Balk & Bernardo, 2011; Hart & Tracy, 2008; Hewett et al., 2011; Tracy & Hart, 2013). As a suitable weight-bearing exercise for those who cannot engage in high-impact activities, it could be hypothesised that yoga may, via various pathways, maintain bone density in some populations (Balk & Bernardo, 2011).

A 5-year longitudinal study assessed BMD using DXA in nine female Bikram yoga teachers (aged 30-59 years) with at least three years of regular teaching and practicing Bikram yoga (Mukherjee et al., 2010; Sangiorgio et al., 2014). Those who were premenopausal at the 5-year follow up showed mean increased BMD at the femoral neck (6.6% ± 5.5%), total hip (2.0% ± 3.8%) and lumbar spine (1% ± 4.7%). Those who were postmenopausal at the 5-year follow up showed a mean decrease in BMD at the femoral neck (-6.0% ± 6.6%), total hip (-8.1% ± 6.1%) and lumbar spine (-5.6% ± 9.1%). The improved total hip BMD in the premenopausal group was significantly higher than the reduction in BMD reported by the postmenopausal group (p = 0.02). These findings are surprising in the premenopausal group; however, the results were as expected in the postmenopausal group due to the age-related decline in BMD. Whether or not participants engaged in additional exercise, altered nutritional intake or took certain medication during the 5-year period was not reported. More rigorous RCTs that incorporate measures such as hormone fluctuations during menopause and changes in nutritional intake could further explain these findings.

Sleep Quality

Quality of sleep is affected by several factors including stress, hormonal imbalances and obesity (Gangwisch et al., 2005). Although exact mechanisms are unknown, both exercise and yoga reportedly encourage healthy sleep patterns (Alexander et al., 2012; Driver & Taylor, 2000; Taibi & Vitiello, 2011). An uncontrolled, observational study examined the acute effects of Bikram yoga practice on the sleep architecture (structure and pattern of sleep) of 13 apparently healthy males and females aged between 18-45 years (Kudesia & Bianchi, 2012). Participants were asked to partake in two to 12 Bikram yoga classes over a period of 14 days to compare sleep patterns (wireless headband and self-report) on the days that participants attended class compared with days that participants did not. Total sleep time, sleep latency (time it takes to fall asleep), and stages of sleep (i.e. REM cycles) were unchanged between practice and non-practice days. On days that participants attended class, the time to return to sleep after naturally occurring nocturnal awakenings was reduced significantly ($p < 0.03$). No study has examined the effect of Bikram yoga on hormones (e.g. melatonin, serotonin, dopamine), which may influence sleep patterns, but this finding could also be influenced by the stress-reducing effect of Bikram yoga that has been observed in a separate study (Hewett et al., 2011). Future research should consider using a cohort prone to sleep disturbances.

Psychological adaptations

Chronic stress is now widely acknowledged as being associated with CVD among a wide range of other chronic conditions. Stress contributes to systemic inflammation via two main pathways, the HPA axis and the sympathetic nervous system (Foss & Dyrstad, 2011; Pasquali et al., 2010). It has been hypothesised that *hatha* yoga practice may attenuate HPA axis and sympathetic hyperactivity, and the associated physiological, inflammatory response, which could lead to a reduction in stress- and inflammation-related illness (Kiecolt-Glaser et al., 2010).

An uncontrolled trial examined the effectiveness of 8-weeks of Bikram yoga (minimum three classes per week) on mindfulness, perceived stress, and physical fitness in 51 apparently healthy men and women (Hewett et al., 2011). Participants (aged 20-54 years) had varying physical activity levels at baseline. At the completion of the trial, mindfulness, evaluated by the Five-Facet Mindfulness Questionnaire (FFMQ), and perceived stress, evaluated by the Perceived Stress Scale (PSS), significantly improved ($p < 0.01$). Mindfulness was negatively and significantly correlated with perceived stress ($r = -0.43$, $p < 0.05$) and with resting heart rate ($r = 0.30$, $p < 0.01$). *Hatha* yoga offers a 'meditation through movement' opportunity much like the practice of Tai Chi (Irwin & Olmstead, 2012), which may contribute to the increased mindfulness and reduction in perceived stress. Although it is hard to know what is responsible for these changes, *hatha* yoga incorporates physical activity as well as relaxation in the same class, and encourages participants to keep the mind present with the movement of the breath and the body in different *asanas*. These qualities may encourage mindfulness, increase vagal tone and reduce perceived stress, and they present opportunities for more robust research examining stress reduction and associated health risks.

Despite major limitations in this study's design, these preliminary findings provide a starting point for understanding Bikram yoga's relationship to stress, and, potentially, stress-related illnesses and chronic disease. Further recommendations for the investigation of psychological outcomes should include the collection of more self-report data as well as physiological outcomes with a known relationship to psychological stress, including heart rate variability (HRV), arterial stiffness, interleukin-6 (IL-6), CRP, and cortisol (Foss & Dyrstad, 2011; Sivasankaran et al., 2006; Yadav et al., 2012). HRV has been shown to improve with some *hatha* yoga interventions (Papp et al., 2013; Satyapriya et al., 2009). HRV also relates to cardiovascular outcomes and may address the relationship between psychological stress and chronic disease. Investigating intervention-related behaviour change may be noteworthy to assess the effects of yoga practice on lifestyle. The findings from this preliminary research warrant further investigation in RCT format considering the contribution stress has towards health and well-being.

Adherence

Adherence data is important to assess the feasibility of any physical activity intervention. It is also crucial in explaining outcome measures that change, or remain the same, as a result of an intervention. For example, a participant who attends one exercise session per week will likely not improve health measures to the same degree that a participant attending four sessions would ("Physical Activity and Public Health: Updated Recommendation for Adults From the American College of Sports Medicine and the American Heart Association," 2007). Only two of the Bikram yoga studies reviewed reported adherence data. The RCT reported a retention rate of 48% in the yoga group (Tracy & Hart, 2013), with an average attendance was 22.5 classes in eight weeks, and dropouts were attributed to scheduling and dissatisfaction with the intervention (Tracy & Hart, 2013). An uncontrolled trial studying mindfulness reported a 64% retention rate, average attendance of 28.6 classes in eight weeks, and the majority of dropouts were due to time commitments (Hewett et al., 2011).

Adverse events

Two trials reported no adverse events (Hunter et al., 2013; Hunter et al., 2013), and all other trials failed to report on adverse events at all, however, Bikram yoga, like any exercise prescription, may be unsafe for certain individuals and medical clearance is advised for at risk individuals (ACSM, 2006; Hunter et al., 2013; Hunter et al., 2013; Lu & Pierre, 2007). Individual cases of adverse events have been reported in three separate case studies (Ferrera et al., 2014; Lu & Pierre, 2007; Reynolds et al., 2012). A letter to the editor of the American Journal of Psychiatry was submitted in 2007 reporting a case study of a 33-year-old man with a history of brief hallucinogen-induced psychosis who experienced a psychotic episode while participating in the Bikram yoga teacher training (Lu & Pierre, 2007). The subject reported feeling dehydrated, eating poorly and was lacking sleep leading up to the episode. Hospital tests (brain MRI, EEG and urine toxicology) all came back normal. The authors suggest that despite reported benefits for some individuals, more intensive styles of yoga (i.e. Bikram yoga) may not be suitable for certain individuals such as those who are psychosis-prone.

The second case study reported on a 34-year-old woman who presented to hospital with breathlessness, muscle cramps, nausea and general malaise from drinking 3.5 litres of water after her first Bikram yoga class (Reynolds et al., 2012). Initial testing (blood gas on air) showed severe hyponatraemia and respiratory alkalosis. After five days in hospital a full recovery was made and the woman was discharged. Bikram yoga instructors should be aware of the risk factors, signs and symptoms of hyponatraemia given the extreme hot and humid conditions in the class, as well as be able to make sound recommendations for rehydration including drinking to one’s thirst (Hew-Butler et al., 2008).

A third case study reported on a healthy 53-year-old man with no CVD risk factors who experienced acute coronary syndrome during a Bikram yoga class (Ferrera et al., 2014).

The man was admitted to hospital and received surgical intervention before being discharged four days later. Males aged ≥ 45 years and women aged ≥ 55 are at increased risk of heart disease (ACSM, 2006) and practitioners in this age group should exercise caution, potentially obtaining doctor's clearance, when starting Bikram yoga, especially if coming from a sedentary lifestyle.

Although these are isolated events it is of great importance to understand the potential risk of participation in any form of exercise for different populations, especially exercise such as Bikram yoga, which has not yet been thoroughly examined with repeated, robust research. Future research should disclose all adverse events, as well as employ satisfactory pre-intervention screenings and medical supervision when required, taking into account the potential risk of Bikram yoga for the given sample population.

3.4 Future recommendations

It appears that Bikram yoga training improves aspects of physical fitness (range of motion, single-leg balance, strength), which can be logically explained by the nature of Bikram yoga, a style of *hatha* yoga. A deeper, scientific examination is required to determine the effect of Bikram yoga on cardiovascular outcomes (cholesterol, fasting blood glucose, arterial stiffness, carotid artery compliance), bone mineral density, sleep quality, pulmonary function, and psychological health (perceived stress, mindfulness). The greatest improvement to the current body of scientific knowledge of Bikram yoga lies in future application of robust research techniques.

Only one study in this review used an RCT design to examine the effects of Bikram yoga. Fundamentally, subsequent Bikram yoga studies should adopt an RCT design in order to add significant contributions to the discussion on the health benefits derived from exercise interventions. Greater adherence to reporting standards, such as CONSORT, may improve reporting and an assessment of study quality from current standards, and would address the pervasive study limitations present in the current body of research including small sample sizes, lack of randomization, confounding variables, and little mention of to the occurrence or lack of adverse events, limitations, and compliance (Moher et al., 2001).

Bikram yoga appears to be an alternative to traditional exercise modalities that may have favourable effects on metabolic markers including blood lipids, insulin resistance and glucose tolerance. This has significant clinical implications for individuals who wish to address dyslipidaemia and glucose management by exploring non-pharmaceutical options. Additionally, those who are unable or unwilling to participate in traditional aerobic exercise and strength training may be able to improve glucose and cholesterol management with Bikram yoga training. In order to maximise the effect of these findings, trial duration and session frequency needs to be addressed in future research. This is more complex than adhering to CONSORT or ACSM guidelines. *Hatha* yoga is a holistic and often variable practice making research hard to quantify and compare to other forms of exercise (Sherman, 2012). Further understanding of the acute adaptations to Bikram yoga is crucial to determine whether or not this form of exercise is an effective intervention compared to current ACSM guidelines for exercise, and disease management and prevention. This would allow for a comparison between Bikram yoga and other exercise modalities. The metabolic cost data reported in this review is very new information, and could be used in future research to determine a specific Bikram yoga prescription, knowing that the prescription will vary depending on the desired outcome measure. Additional acute data, for example, blood glucose before, during, and after a session, would also contribute to the development of Bikram yoga prescription guidelines for specific outcome measures.

Finally, most of the current studies have examined apparently healthy adults. Unsurprisingly, health-related outcomes, for example resting heart rate and blood pressure, remain unchanged in healthy participants. It is hard to determine the effects of an exercise intervention in cohorts who indicators of health and well-being within healthy ranges at baseline. Significant findings in the one study to the authors' knowledge that has examined the effects of Bikram yoga on the unhealthy (obese) individual strengthen the recommendation to examine cardiometabolic adaptations in unhealthy populations (Hunter et al., 2013). Physiological adaptations should be examined in cohorts with physiological imbalances, such as dyslipidaemia, hypertension and insulin resistance, to better understand intervention-related adaptations and their influence on the progression of chronic disease.

3.5 Conclusion

This review describes the available Bikram yoga literature in order to better understand the effects of this form of exercise, and to suggest ways to improve future research in this field. Topics that have not yet been investigated include the effects of Bikram yoga on the physiological markers of stress, cognition, depression and anxiety, inflammation, QoL and behaviour change. Additionally, further investigation into the acute effects of Bikram yoga practice would deepen the understanding of the physiological adaptations. Continued research will greatly improve the scientific understanding of Bikram yoga practice, which will help to determine whether or not it can be considered another tool to address the concerning, growing prevalence of chronic disease and stress-related illness.

Chapter 4

General Methods

4.1 Study design

This was a parallel-arm RCT comparing the outcomes of participants assigned to an experimental treatment group (Bikram yoga) to those assigned to a no-treatment control group. The intervention period was 16 weeks, and the assessment of primary and secondary outcomes was completed at baseline (week zero) and following the intervention period (week 17). Baseline and follow-up assessments were completed at the University of Canberra (UC) and Capital Pathology collection centres. The Western Sydney University (H10549) and University of Canberra Human Research Ethics Committees (H10549-14/009174) approved all procedures, and written informed consent (Appendix 2) was obtained from all participants. The study was retrospectively registered with the *Australian New Zealand Clinical Trials Registry* on 04 July 2016. (http://www.anzctr.org.au/ACTRN12616000867493.aspx). All outputs are reported according to guidelines established by The CONSORT group (Moher et al., 2001).

4.2 Study population

4.2.1 Recruitment

Participants were recruited between August 2014 and September 2015 in the Australian Capital Territory (ACT) using flyers (posted at local community dwellings, shared via social media and distributed via department-wide intranet systems) and word of mouth referral. Individuals who contacted the principal investigator were given a participant information sheet (Appendix 3) and those who expressed further interest assessed for eligibility using a standardised screening process and questionnaires administered via email. Eligibility was confirmed via telephone interview. An individual who responded 'yes' to any question on the *Physical Activity Readiness Questionnaire* (PAR-Q) ("Canadian Society for Exercise Physiology. Physical Activity Readiness Questionnaire (PAR-Q)," 2002) within the medical screening form (Appendix 4) required medical clearance prior to participating in the trial. The cost of this visit to the general practitioner was covered by the participant. Data collection was completed in January 2016.

4.2.2 Medical screening

Eligibility criteria: (1) Adult (≥18 years); (2) sedentary (i.e. <150 min of moderate-intensity exercise per week (ACSM, 2006) for greater than six months); (3) a score >14 on the stress component of the Depression, Anxiety and Stress Scale (DASS-21) (Lovibond & Lovibond, 1995) indicating mild stress (Appendix 5; (4) no diagnosed chronic diseases; (5) no acute or chronic medical conditions which would make Bikram yoga potentially hazardous (i.e. pregnancy) or primary outcome difficult to assess (i.e. pacemaker influences on HRV); (6) able to attend three to five Bikram yoga classes per week for 16 weeks; (7) cognition and English language sufficient to understand research procedures and provide informed consent; (8) no participation in Bikram yoga in the past six months.

Waist circumference greater than 80cm (women) and 94cm (men) was included in the original eligibility criteria, however, due to low enrolment, waist circumference requirements were dropped in July 2015 to achieve an adequate sample size.

4.2.3 Randomisation

Participants were randomised via a computer-generated list (www.randomization.com) stratified by sex and age (<50yr; >50yr). An investigator not involved in testing or the delivery of the intervention prepared the randomisation assignments. Group assignments were handed to participants in sealed, opaque envelopes upon the completion of baseline testing. Participants opened the envelope and showed the primary investigator the group assignment, which was then recorded.

4.3 Study treatments

4.3.1 Experimental group

Participants in the experimental group engaged in 16 weeks of Bikram yoga classes at either of two affiliated Bikram yoga studios in Canberra, ACT. Participants were instructed to attend between three to five regularly scheduled classes per week. Certified Bikram yoga teachers instructed all classes using a set instructional dialogue. Teachers were trained in First Aid and CPR. Classes were 90 minutes in duration and held in a temperature-controlled room (40.6°C, 40% relative humidity). The Bikram yoga practice consisted of 45-50 minutes of standing *asanas* starting with a deep breathing exercise, and 40-45 minutes of floor-based *asanas*, including a quick, forceful breathing exercise to finish. All but the last *asana* (spine-twisting) were performed twice (Appendix 1). *Savasana* (a restorative, relaxation posture) was performed between *asanas* in the floor series and at the end of class (Choudhury, 2007).

4.3.2 Control group

Participants in the control group were given no specific instructions about Bikram yoga practice and were asked to continue with current lifestyle practices for the duration of the intervention. Control group participants were offered a complimentary 10-class pass at one of the participating studios upon completion of the intervention.

4.4 Outcome measures

Two trained researchers, including the candidate, assessed all outcome measures, with the exception of haematological data, which were collected and analysed on a separate day by Capital Pathology, a National Association of Testing Authorities (NATA) certified blood collection centre (blinded). Psychological outcome measures were also assessed at the mid-point of the intervention (week eight). Participants were instructed to refrain from exercise for 48 hours prior to each testing session, including the blood collection appointment, to avoid a possible confounding effect caused by acute exercise on outcome measures. Participants were also instructed to refrain from food, caffeine and alcohol within 12 hours of testing sessions, including the blood collection appointment. Measurements took place in the morning to maximise adherence to fasting protocols, and in order to better control the level of participant hydration, which can alter body composition measurements (Nana et al., 2012). In the rare circumstance where fasting guidelines were not followed, appointments were rescheduled. Follow up testing was scheduled at the same time of day as baseline testing. Assessments lasted for approximately 1.5 hours for each participant and were completed in the following order at each testing time point: anthropometrics, dual-energy x-ray absorptiometry (DXA) measures, blood pressure, heart rate, augmentation index (AIx), heart rate variability (HRV) measures and psychological questionnaires.

4.4.1 Physiological outcomes

4.4.1.1 Heart rate variability and secondary haemodynamic outcomes

HRV data was collected in a quiet room using the SphygmoCor system (SphygmoCor, AtCor Medical Pty, Sydney, Australia). The data collection protocol adhered to Task Force for Pacing and Electrophysiology guidelines (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). After 10 minutes of supine rest with a regular and calm breathing pattern the SphygmoCor system captured electrocardiographic (ECG) data for 10 minutes. From the ECG recording the following time domain variables were calculated from RR intervals: standard deviation of normal-to-normal intervals (SDNN) and HRV triangular index (TI). Frequency domain variables, including total, high frequency (HF) and low frequency (LF) power components of HRV and LF/HF ratio were derived from spectral analysis of successive RR intervals. This technique provides quantitative estimates of sympathetic and parasympathetic (vagal) neural influences on the heart. Respiration rate was not measured. The primary outcome was the HF power component of HRV (measured in absolute units; ms^2), while the other HRV measures were collected as secondary outcomes.

Following resting and prior to HRV data collection secondary haemodynamic outcomes were assessed including systolic and diastolic blood pressure, resting heart rate and AIx. Three brachial blood pressure readings were measured and the average of the three was recorded (M10-IT, Omron Inc., Japan). Resting heart rate was analysed with each blood pressure measurement and the average of the three measures recorded. AIx was measured at the radial artery using the SphygmoCor System (AtCor Medical Pty, Sydney, Australia) and hand-held, high fidelity tonometer (Millar Instruments, Houston, Texas). AIx describes the augmentation of aortic pressure by reflected pressure waves at the radial artery and is a highly reproducible method (Wilkinson et al., 1998). AIx is calculated by dividing augmentation pressure by pulse pressure and multiplying by 100, and the SphygmoCor algorithm normalises AIx to a heart rate of 75 beats per minute to minimise the effects of confounding variables heart rate and ejection fraction (Sharman et al., 2009). AIx has been used to measure arterial stiffness in healthy and diseased cohorts (Edwards & Lang, 2005; Mustata et al., 2004). Larger values indicate greater arterial stiffness.

4.4.1.2 Anthropometric measures and body composition

Height and weight were measured using a Seca 763 Electronic weighing and measuring scale (Seca, Hamburg, Germany) and BMI was computed from these measures (ACSM, 2010). Waist circumference was measured using a standardised procedure (ACSM, 2010). Body composition was assessed using a Lunar Prodigy Pro™ Dual-energy X-ray Absorptiometry (DXA) scan analysed with manufacturer software (enCORE™ v 14.1 software, GE Healthcare, Sydney, Australia). DXA scanning was completed in accordance with the University of Canberra's DXA scanning protocol and has been validated in previous research (Nana et al., 2012, 2013). Participants were scanned prior to any exercise being completed and wore minimal clothing with all jewellery and metal objects removed. Data from participants too large to fit within the scanning region was estimated using the software estimate function. Percent body fat (%), fat mass (g), lean mass (g), fat free mass (g), and bone mineral content (g) were reported for all participants.

4.4.1.3 Haematological measures

Participants were required to schedule a morning appointment (fasting sample) with one of Capital Pathology's many collection centres across the Australian Capital Territory and New South Wales during the week of baseline testing. High-sensitivity c-reactive protein (hsCRP), total cholesterol, low-density- and high-density lipoprotein cholesterol (LDL and HDL), total cholesterol to HDL ratio, triglycerides, and fasting blood glucose were collected and assessed using standard blood collection procedures and assays (coefficients of variation (CV): 2.0% – 4.2%). All procedures for analysis were performed on the Roche Cobas c8000 except for CRP which was analysed using the C16000 (CV: 3.7%). Total cholesterol was assessed using an enzymatic colorimetric assay (CV: 2.0%), HDL was assessed using a homogeneous enzymatic colorimetric assay (CV: 2.6%), triglycerides were assessed using an enzymatic colorimetric assay (CV: 4.2%), and glucose was assessed using an enzymatic reference method with hexokinase assay (CV: 2.0%). LDL was calculated using the Friedewalds calculation: LDL = total cholesterol – HDL – triglyceride/2.2.

4.4.2 Psychological outcomes

4.4.2.1 Perceived psychological stress

Psychological stress was assessed with the 10-item Perceived Stress Scale (PSS) (Cohen et al., 1983). The 10-item PSS (Appendix 6) has been widely used and is a valid and reliable tool to assess perceived stress (Cohen, 1988; Cohen et al., 1983; Roberti et al., 2006). The PSS has been used in studies that have observed the relationship between stress and yoga (Granath et al., 2006; Michalsen et al., 2005). A Likert-scale is used to record responses to each question, and the questions are designed to measure the extent to which events in one's life in the past month were perceived as stressful. Scores range from zero to 40 with higher scores indicating higher levels of perceived stress.

4.4.2.2 General self-efficacy

The 10-item General Self-Efficacy scale (GSE) was used to assess general self-efficacy (Appendix 7) (Schwarzer & Jerusalem, 1995). The GSE scale has been shown to be a reliable construct to measure general self-efficacy across different cultures (Schwarzer et al., 1999). The questionnaire asked participants to rate on a 4-point scale how true certain statements were (e.g. "I am confident that I could deal efficiently with unexpected events"). The GSE is scored on a 4-point Likert-scale with higher scores indicating higher general self-efficacy.

4.4.2.3 Exercise self-efficacy

A 5-item questionnaire was used to assess exercise self-efficacy (internal consistency, i.e. Cronbach's alpha = 0.88) (Schwarzer & Renner). The questionnaire (Appendix 8) asked participants to rate on a 4-point scale how certain they were that they could manage to carry out their exercise intentions when certain barriers arose (e.g. feeling tired or being busy). The questions are scored on a 4-point Likert-scale with higher scores indicating higher exercise self-efficacy.

4.4.2.4 Quality of life

General psychological health and quality of life was assessed by the *RAND 36-Item Health Survey 1.0* (SF36), a generic health status measure that assesses eight domains of quality of life (Appendix 9) (Stewart et al., 1988; Ware & Sherbourne, 1992). The domains are physical functioning, bodily pain, role limitations due to physical health problems (physical role limitations), role limitations due to emotional problems (emotional role limitations), emotional well-being, social functioning, energy/fatigue, and general health. The SF36 is reliable, has construct validity and the domains have been shown to have good internal consistency in apparently healthy populations (Brazier et al., 1992; Jenkinson et al., 1993; Stewart et al., 1988). Responses in each domain were coded to fit on a scoring scale ranging from zero to 100. The scores in each domain were then summed and averaged to produce a single score for each of the eight domains to reflect health status.

4.5 Clinical covariates

The International Physical Activity Questionnaire (IPAQ) was used to assess levels of non-intervention related physical activity in the experimental and control groups at week zero and week 17 (Appendix 10). The IPAQ is a valid and reliable method for assessing physical activity over a 7-day period (Craig et al., 2003). A 7-day food diary was administered in weeks zero and 17 (Appendix 11) and diet data was analysed using FoodWorks (version 8, Xyris Software Pty Ltd, Australia) to assess changes in macronutrients (i.e. carbohydrates, proteins and fats). Additional factors potentially related to the adaptations under investigation in this RCT were extracted during the recruitment and medical screening process and baseline testing by means of standard questionnaires. These factors were entered into analytic models as appropriate and included demographic characteristics (i.e. age, gender, smoking history), number and type of chronic diseases, previous *hatha* yoga experience and medication usage.

4.6 Changes in health status, adverse events and compliance

Weekly status checks were administered via phone, email or in person throughout intervention period to check for major exercise or diet changes and changes in health status in both groups (Appendix 12). All participants were also queried via the status check if they had experienced any adverse events during the week preceding. Any participants experiencing an adverse event were referred to a qualified health care practitioner for appropriate assessment and treatment. All adverse events were documented and reported. Attendance in the experimental group was recorded electronically upon arrival at each respective studio via an online booking system controlled by the staff member at reception. Attendance was reported as total number of sessions completed.

4.7 Statistical analyses

Primary analysis was undertaken using intention-to-treat regardless of dropout or level of adherence. Missing data at week 17 was imputed using the last observation carry forward method. Missing data at week eight was imputed carrying the last observation backward. Outcomes data is presented as the mean ± standard deviation (SD) with effect size and 95% confidence intervals (CIs). Baseline characteristics were compared using t-tests (continuous variables) and chi square tests (non-continuous variables). Natural logarithm transformations were applied to variables showing positive skew, and accepted where normality was improved. Mean differences in physiological outcomes between groups at completion were examined using analysis of covariance (ANCOVA) adjusting for the baseline value of the outcome variable. Mean differences in psychological outcomes over time were examined via repeated measures analysis of variance (ANOVA). ANCOVA was used to interpret statistically significant repeated measures ANOVA results, comparing between group changes from week zero to week eight and from week eight to week 17. Pearson's correlation coefficients (r) were used to examine baseline associations between the primary outcome and secondary outcomes with p-values reported for the hypothesis testing that the correlation was equal to zero. Regression analyses were used to examine predictors of adherence and the effect of attendance on adaptation of outcomes. A p-value less than 0.05 was considered indicative of statistical significance with p-values less than 0.10 providing weaker evidence of association. For psychological outcomes, significance was interpreted using the Greenhouse-Geisser p value. Effect sizes were summarised as partial eta-squared statistics (η_p^2).

Attendance data was analysed with minor adjustments to three attendance values to investigate attendance in relation to the minimum required classes (48 classes). Attendance scores for participants who attended more than 48 classes (n = 3) were reassigned a score of 48. Overall adherence (%) to the intervention was calculated by taking the average number of classes attended, dividing that number by the minimum number of required classes (i.e. 48 classes), and multiplying by 100. Analysis of covariance (ANCOVA) was applied using continuous and categorical (i.e. age, depression scores) predictors as covariates and 'attendance' as the dependent variable. A p-value less than 0.05 was considered indicative of statistical significance with p-values less than 0.10 providing weaker evidence of association. Baseline variables that predicted attendance scores with significance of $p < 0.10$ were checked for co-linearity. Variables with correlation coefficients of $r < 0.70$ were selected for inclusion in the multi-variable analysis. All analyses were carried out using SPSS (IBM©, Version 23).

4.8 Sample size

To date there have been no studies investigating the effect of Bikram yoga on parameters of HRV and therefore this research was largely exploratory. However, it has been shown that yoga induces adaptations that are similar to those achieved with conventional exercise (Ross & Thomas, 2010). Therefore, data derived from an aerobic exercise intervention trial in an apparently healthy adult cohort (Carter et al., 2003) was used to compute statistical power *a priori* using the non-commercial statistical power analysis program G*Power. The control group was expected to experience no change in the HF spectral power component from baseline ($205.7 \pm 205.7 ms^2$) while the experimental group was expected to increase this measure following the 16-week yoga intervention ($568.0 \pm 696.0\ ms^2$). Setting an alpha level of 0.05, approximately 56 participants (28 per group) provided 80% power to detect a statistically significant difference between groups. Recruitment was inflated to 68 participants to enable a 15% participant attrition rate.

Chapter 5

Effect Of A 16-Week Bikram Yoga Program On Heart Rate Variability And Associated Cardiovascular Disease Risk Factors In Stressed And Sedentary Adults: A Randomised Controlled Trial

This chapter has been published in BMC Complementary and Alternative Medicine:

Hewett, Z.L., Pumpa, K.L., Smith, C.A., Fahey, P.P., Cheema, B.S. (2017). Effect of a 16-week Bikram yoga program on heart rate variability and associated cardiovascular disease risk factors in stressed and sedentary adults: A randomised controlled trial. *BMC Complementary and Alternative Medicine*, 2017; 17(226). doi: 10.1186/s12906-017-1740-1

5.1 Abstract

Background: Chronic activation of the stress-response can contribute to cardiovascular disease risk, particularly in sedentary individuals. This study investigated the effect of a Bikram yoga intervention on the high frequency power component of heart rate variability (HRV) and associated cardiovascular disease (CVD) risk factors (i.e. additional domains of HRV, haemodynamic, haematological, anthropometric and body composition outcome measures) in stressed and sedentary adults.

Methods: Eligible adults were randomised to an experimental group (n = 29) or a no treatment control group (n = 34). Experimental group participants were instructed to attend three to five supervised Bikram yoga classes per week for 16 weeks at local studios. Outcome measures were assessed at baseline (week zero) and completion (week 17).

Results: Sixty-three adults (37.2 ± 10.8 years, 79% women) were included in the intention-to-treat analysis. The experimental group attended 27 ± 18 classes. Analyses of covariance revealed no significant change in the high-frequency component of HRV (p = 0.912, η_p^2 = 0.000) or in any secondary outcome measure between groups over time. However, regression analyses revealed that higher attendance in the experimental group was associated with significant reductions in diastolic blood pressure (p = 0.039; η_p^2 = 0.154), body fat percentage (p = 0.001, η_p^2 = 0.379), fat mass (p = 0.003, η_p^2 = 0.294) and body mass index (p = 0.05, η_p^2 = 0.139).

Conclusions: A 16-week Bikram yoga program did not increase the high frequency power component of HRV or any other CVD risk factors investigated. As revealed by post hoc analyses, low adherence likely contributed to the null effects. Future studies are required to address barriers to adherence to better elucidate the dose-response effects of Bikram yoga practice as a medium to lower stress-related CVD risk.

5.2 Introduction

Chronic psychological stress is associated with increased risk of cardiovascular disease (CVD) and associated mortality (Dishman et al., 2000; Foss & Dyrstad, 2011; Thayer & Lane, 2007). During stress, the sympathetic nervous system (SNS) mediates neuroendocrine changes via the hypothalamic-pituitary-adrenal (HPA) axis (Bose et al., 2009; Charmandari et al., 2005). This 'fight-or-flight' response includes the release of stress hormones (e.g. cortisol, aldosterone, epinephrine), which in turn increase heart rate, blood pressure, and blood lipid and glucose concentrations, preparing the body for physical exertion. Chronic SNS activity, via this mechanism, can contribute to atherosclerosis and CVD, particularly in individuals who are physically inactive (sedentary) (Chandola et al., 2008; Chrousos, 2000).

Heart rate variability (HRV) is the instantaneous variation in heart rhythm due to autonomic nervous system (ANS) influences on the sinoatrial node. Low HRV is associated with a reduced capacity to adjust to environmental demands (Ryan et al., 2011; Thayer & Lane, 2009) and increased CVD and mortality (Nolan et al., 1998; Thayer & Lane, 2007, 2009). Moreover, low HRV is consistently noted in individuals who are sedentary (Dietrich et al., 2008), overweight-obese (Andrew et al., 2013; Lampert et al., 2008) and psychologically stressed (Dishman et al., 2000). Specific components of HRV can denote the relative input of each branch of the ANS. Vagal activity is reflected in the high frequency (HF) spectral power component of HRV (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996).

Hatha yoga is a branch of yoga originating from India that emphasizes the performance of physical postures (*asanas*) (Borg-Olivier & Machliss, 2011). Several studies have reported that *hatha* yoga can reduce perceived stress (Chong et al., 2011) and salivary cortisol, a main effector of the SNS and HPA axis pathways (Banasik et al., 2011; Rocha et al., 2012; West et al., 2004), as well as improve cardiometabolic health (Chu et al., 2016). Studies have also reported that a single session of *hatha* yoga can acutely increase the HF power component of HRV (Huang et al., 2013; Papp et al., 2013; Satyapriya et al., 2009; Sawane & Gupta, 2015). However, the chronic effects of *hatha* yoga training on HRV remain inconclusive due to a lack of robust clinical trials (Posadzki et al., 2015).

Bikram yoga is a specific system of *hatha* yoga that incorporates a 90-minute, unchanging sequence of *asanas* performed in a heated environment (40.6°C, 40% humidity) (Choudhury, 2007). A randomised controlled trial (RCT) of Bikram yoga reported reduced reactivity to stress (cortisol) in women at risk for obesity-related illnesses (Hopkins et al., 2016), while uncontrolled trials have shown that eight weeks of Bikram yoga can reduce perceived stress in apparently healthy adults (Hewett et al., 2011), reduce blood lipids (i.e. total and low-density lipoprotein cholesterol) and arterial stiffness in healthy adults (Hunter et al., 2013) and improve glucose tolerance, body mass and body mass index (BMI) in obese adults (Hunter et al., 2013). The heated environment is a cornerstone feature of Bikram yoga and may aid in its effectiveness in abating CVD risk factors. For example, recent prospective data indicates that more frequent sauna bathing is associated with reduced risk of sudden cardiac death, coronary heart disease, and all-cause mortality in males (Laukkanen et al., 2015). Further, preliminary evidence suggests that thermal exposure (sauna bathing and spa treatment) may lead to increased resting HRV in healthy subjects and athletes (Corsini et al., 2015; Stanley et al., 2015).

To date, no study has investigated the effect of Bikram yoga on any HRV outcomes (Hewett et al., 2015). Therefore, the purpose of this study was to investigate the effect of a 16-week Bikram yoga intervention on the HF power component of HRV and associated CVD risk factors in a population of stressed and sedentary adults. We hypothesised that participants randomised to the intervention would significantly increase the HF power component and experience significant adaptation of associated CVD risk factors, including additional HRV measures (time and frequency domains) and a range of haemodynamic, haematological, anthropometric and body composition outcomes compared to a no treatment control.

5.3 Methods

Study Design

This 16-week, parallel-arm RCT compared the outcomes of participants randomised to an experimental group (Bikram yoga) or a no-treatment control group. Primary and secondary outcomes were collected prior to and following the intervention period at weeks zero and 17, respectively. The Western Sydney University (H10549) and University of Canberra Human Research Ethics Committees (H10549-14/009174) approved all procedures and written informed consent was obtained from all participants.

Participants and recruitment

Eligibility criteria: (1) Adult (≥18 years); (2) sedentary (i.e. <150 min of moderate-intensity exercise per week (ACSM, 2006) for greater than six months); (3) a score >14 on the stress component of the Depression, Anxiety and Stress Scale (DASS-21) (Lovibond & Lovibond, 1995) indicating mild stress; (4) no diagnosed chronic diseases; (5) no acute or chronic medical conditions which would make Bikram yoga potentially hazardous (i.e. pregnancy) or primary outcome difficult to assess (i.e. pacemaker influences on HRV); (6) able to attend three to five Bikram yoga classes per week for 16 weeks; (7) cognition and English language sufficient to understand research procedures and provide informed consent; (8) no participation in Bikram yoga in the past six months. Original inclusion criteria included “waist circumference ≥ 94cm for men; ≥ 80cm for women” but was removed due to low rate of recruitment.

Participants were recruited between August 2014 and September 2015 in the Australian Capital Territory (ACT) using flyers (posted at local community dwellings, and shared via social media) and word of mouth referral. Individuals who contacted the principal investigator and expressed interest were assessed for eligibility using a standardised screening process and questionnaires administered via email and telephone interview. An individual who responded ‘yes’ to any question on the *Physical Activity Readiness Questionnaire* (PAR-Q) ("Canadian Society for Exercise Physiology. Physical Activity Readiness Questionnaire (PAR-Q)," 2002) required medical clearance prior to participating in the trial. Data collection was completed in January 2016.

Sample size

To date there has been no study investigating the effect of Bikram yoga on parameters of HRV. Therefore, we based our sample size estimate on results derived from studies investigating the effect of aerobic exercise training on HRV in apparently healthy adults (Carter et al., 2003). The experimental group was expected to increase the HF component of HRV following the 16-week yoga intervention (568.0 ± 696.0 ms^2) and the control group was expected to experience no change (205.7 ± 290.5 ms^2). With a one-sided alpha level of 0.05, at least 56 participants (28 per group) were required to provide 80% power to detect a statistically significant difference between groups. Recruitment was inflated to 68 participants to enable a 15% participant attrition rate.

Randomisation

Participants were randomised via a computer-generated list (www.randomization.com) stratified by sex and age (< 50yr; ≥ 50yr). An investigator not involved in testing or the delivery of the intervention prepared the randomization assignments. Group assignments were delivered to participants in person in sealed envelopes upon the completion of baseline testing.

Interventions

Experimental group

Participants in the experimental group engaged in 16-weeks of Bikram yoga classes (Figure 5.1) at either of two affiliated Bikram yoga studios in Canberra, ACT. Participants were instructed to attend between three to five regularly scheduled classes per week. Certified Bikram yoga teachers instructed all classes using a set instructional dialogue. Classes were 90 minutes in duration and held in a temperature-controlled room (40.6°C, 40% humidity). The Bikram yoga practice consisted of 45-50 minutes of standing *asanas* starting with a deep breathing exercise, and 40-45 minutes of floor-based *asanas*, including a quick, forceful breathing exercise to finish. All but the last *asana* (spine-twisting) were performed twice. *Savasana* (a restorative, relaxation posture) was performed between *asanas* in the floor series and at the end of class (Choudhury, 2007).

Control group

Participants in the control group were instructed to maintain current lifestyle practices and were not provided any information or instructions about Bikram yoga practice. However, participants were informed during recruitment and screening that the control group participants would be provided a complimentary 10-class pass at one of the participating studios upon completion of the trial.

Figure 5.1 Bikram yoga sequence of *asanas*

Outcome measures

Two trained researchers collected all outcome measures at the University of Canberra, with the exception of haematological data, which were collected and analysed on a separate day by Capital Pathology, a National Association of Testing Authorities (NATA) certified blood collection centre (blinded). Participants were instructed to fast overnight (12 hours) and refrain from exercise for 48 hours prior to both of the two testing session appointment and the blood test appointment. Appointments were rescheduled if these instructions were not followed. Follow up testing was scheduled at the same time of day as baseline testing to minimize the effect of diurnal variation.

Heart rate variability outcomes

HRV was measured in a quiet room according to guidelines developed by the Task Force for Pacing and Electrophysiology (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). After 10 minutes of supine rest with a regular and calm breathing pattern, a continuous 10-minute ECG recording was collected using the SphygmoCor system and HRV software (SphygmoCor, AtCor Medical Pty, Sydney, Australia). From the ECG recording, the following time domain variables were calculated from r-wave to r-wave (RR) intervals: standard deviation of normal-to-normal (NN) intervals (SDNN), root mean square of successive differences between adjacent NN intervals (RMSSD), the proportion of the number of pairs of successive NN intervals that differ by 50ms divided by the total NN intervals (pNN50) and HRV Triangular Index. Frequency domain variables, including HF and LF power (absolute), LF:HF and total power were derived from spectral analysis of successive RR intervals. The primary outcome of the present study was the HF spectral power component of HRV (measured in absolute units; ms^2), while the other HRV measures were secondary outcomes.

Haemodynamic outcomes

Resting brachial blood pressure (systolic and diastolic) and heart rate were assessed after lying for 10 minutes in a supine position using an automatic monitor (M10-IT, Omron Inc., Japan). Augmentation index (AIx) was then measured in this position at the radial artery using the SphygmoCor System (AtCor Medical Pty, Sydney, Australia) and hand-held, high fidelity tonometer (Millar Instruments, Houston, Texas). AIx data was normalised to a heart rate of 75 beats per minute to minimize the effects of confounding variables heart rate and ejection fraction (Sharman et al., 2009).

Haematological outcomes

High-sensitivity c-reactive protein (hsCRP), triglycerides, total cholesterol, low-density- and high-density lipoprotein cholesterol (LDL and HDL), total cholesterol to HDL ratio and fasting blood glucose were collected and assessed using standard blood collection procedures and assays (coefficients of variation: 2.0% – 4.2%).

Anthropometrics and body composition outcomes

Height and weight were measured using a Seca 763 Electronic weighing and measuring scale (Seca, Hamburg, Germany) and BMI was computed from these measures (ACSM, 2010). Waist circumference was measured using a standardised procedure (ACSM, 2010). Body composition was assessed using a Lunar Prodigy Pro™ Dual-energy X-ray Absorptiometry (DXA) scan analysed with manufacturer software (enCORE™ v 14.1 software, GE Healthcare, Sydney, Australia). DXA scanning was completed in accordance with the University of Canberra's DXA scanning protocol and has been validated in previous research (Nana et al., 2012, 2013). Participants were scanned prior to any exercise being completed and wore minimal clothing with all jewellery and metal objects removed. Data from participants too large to fit within the scanning region was estimated using the software estimate function. Percent body fat (%), fat mass (g), lean mass (g), fat mass (g), and bone mineral content (g) were reported for all participants.

Health status covariates, attendance and adverse events

Weekly status checks administered via phone, email or in person throughout intervention period were used to check for major exercise or diet changes and adverse events in the experimental and control group. Participants who experienced an adverse event were advised to visit a qualified health care practitioner for assessment and treatment. A 7-day food diary was also completed in weeks zero and 17 and analysed using FoodWorks (version 8, Xyris Software Pty Ltd, Australia) to assess changes in diet. Attendance in the experimental group was recorded electronically upon arrival at each respective studio via an online booking system controlled by the staff member at reception. Attendance was reported as total number of sessions completed.

Statistical Analyses

Primary analysis was undertaken using intention-to-treat regardless of dropout or level of adherence. Missing data at week 17 was imputed using the last observation carry forward method. Outcomes data is presented as the mean ± standard deviation (SD) with effect size and 95% confidence intervals (CIs). Baseline characteristics were compared using t-tests (continuous variables) and chi square tests (categorical variables). Natural logarithm transformations were applied to variables showing positive skew, and accepted where normality was improved. Mean differences in outcomes between groups at completion were examined using analysis of covariance (ANCOVA) adjusting for the baseline value of the outcome variable. Pearson's correlation coefficients (r) were used to examine baseline associations between the primary outcome and secondary outcomes with

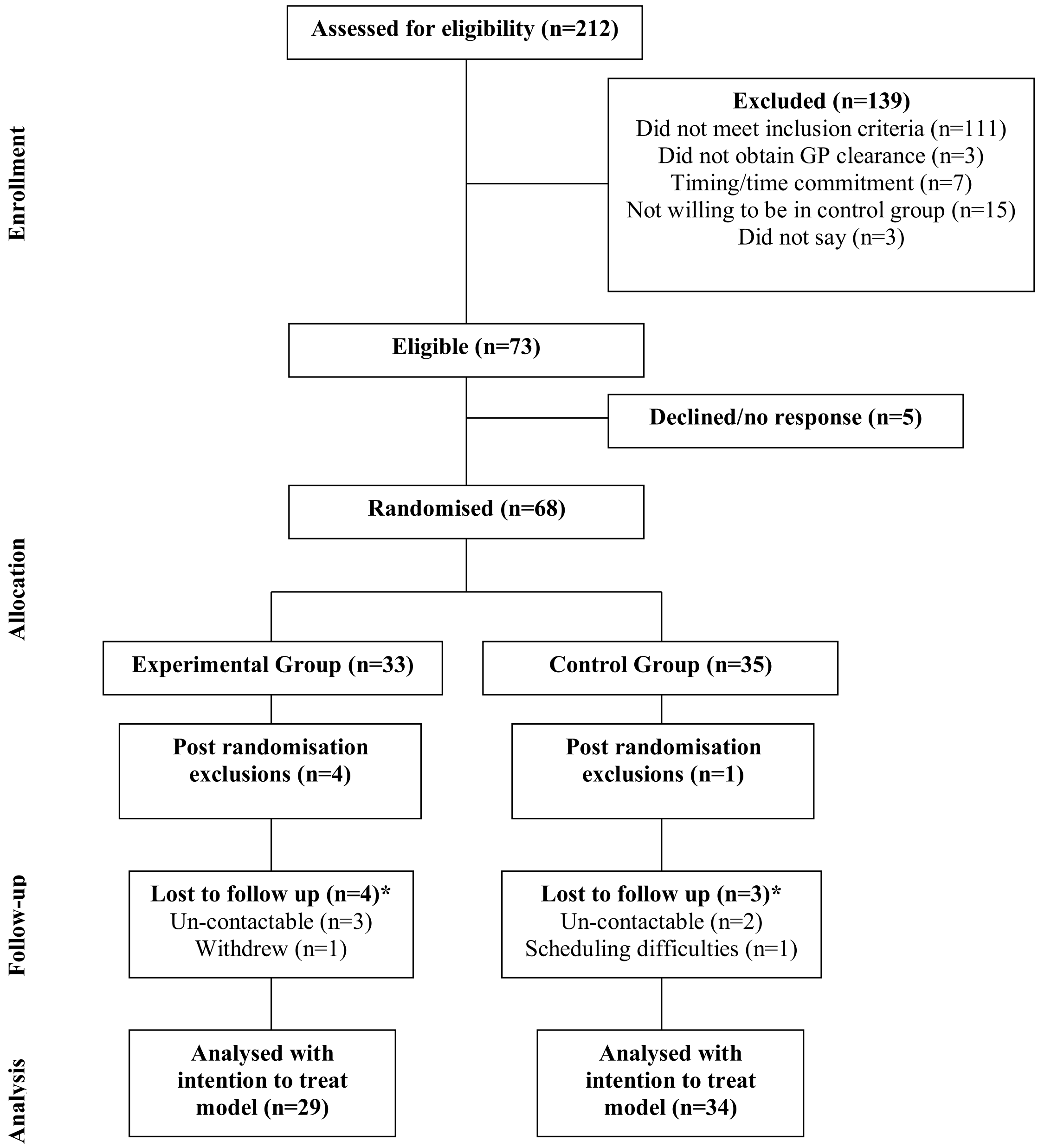
p-values reported for the hypothesis testing that the correlation was equal to zero. Regression analyses were used to examine the effect of attendance on outcomes. A p-value less than 0.05 was considered indicative of statistical significance with p-values less than 0.10 providing weaker evidence of association. Effect sizes are summarised as partial eta-squared (η_p^2) statistics. All analyses were carried out using SPSS (IBM©, Version 23).

5.4 Results

Participants

Two-hundred and twelve individuals contacted the principal investigator and were reviewed for eligibility; 139 were deemed ineligible for reasons presented in Figure 5.2. Of 73 eligible individuals, 68 provided written informed consent and were randomised to either the experimental or control group. Four participants in the experimental group and one participant from the control group were excluded from analysis post-randomisation after re-calculation of the DASS-21 stress scores (inclusion criterion score not met). Further, four participants in the experimental group and three participants in the control group did not return for follow-up testing (week 17).

Figure 5.2 Flow of Participants



*Baseline data carried forward for three participants in each group lost to follow-up for intention-to-treat analysis.

Baseline characteristics

At baseline, there were no significant differences between groups in any of the descriptive characteristics presented in Table 5.1. Participants ranged from 19 to 64 years of age. The majority of the cohort (87%) was under 50 years of age (55/63) and 79% of the cohort was comprised of women (50/63). Further, 43% of the cohort (27/63) meet the clinical criteria for obesity according to BMI >30kg/m^2. The average DASS-21 stress score for the total cohort indicated a moderate level of stress (23.8 ± 6.0). Nearly 70% of the total cohort had no prior Bikram yoga experience while 90% had engaged in less than five Bikram yoga classes previously.

Table 5.1: Baseline characteristics

Characteristic	Total cohort (n = 63)	Yoga group (n = 29)	Control group (n= 34)
Age (y)	37.2 ±10.8	38.2 ± 10.1	36.3 ± 11.4
Women (n; %)	50; 79%	23; 79%	27; 79%
Body weight (kg)	88.5 ± 21.0	86.4 ± 21.2	90.4 ± 21.0
Body mass index (BMI) (kg/m^2)	30.5 ± 6.2	29.9 ± 6.2	30.9 ± 6.3
Obese (BMI 30+) (n; %)	27; 43%	11; 38%	16; 47%
Waist circumference (cm)	94.7 ± 14.7	93.9 ± 14.5	95.3 ± 15.1
Stress score (DASS-21)	23.8 ± 6.0	23.3 ± 6.0	24.3 ± 6.1
Current smoker or quit in last 6 months (n; %)	3; 5%	1; 3%	2; 6%

Continuous data presented as mean ± standard deviation
Abbreviations: DASS = Depression-Anxiety-Stress-Scale (stress categories: 15-18 = mild, 19-25 = moderate, 26-33 = severe, 34+ = extremely severe)

Health status covariates, attendance and adverse events

There were no significant changes between groups over time in total energy, carbohydrate, protein and fat intake according to the 7-day food diary. Weekly status checks revealed that three participants in the control group engaged in structured exercise programs during the intervention period (i.e. aerobic and/or strength training).

The experimental group attended an average of 27 ± 18 (range: 4 to 79) of a possible 80 classes. Nine participants attended >80% of the minimum three required classes per week (i.e. >38 of 48 classes). Ten participants attended a total of 16 or fewer classes (i.e. less than one class per week) over the intervention period.

Six participants in the experimental group experienced exacerbation of a pre-existing condition during the trial (i.e. back pain, foot pain, knee pain, calf pain, psychological discomfort). All six participants were advised to consult their general practitioner. Three of these participants discontinued the intervention. The other three continued attending some classes when they could, with modifications made to *asanas* if needed. One additional participant discontinued the intervention after a non-intervention related event (sprained ankle). In the control group, one participant reported a meniscus tear incurred by stepping awkwardly.

Baseline associations with the primary outcome

After logarithmic transformation (Ln) to correct skewed distributions, the Ln HF power component of HRV was found to be positively correlated with all secondary HRV outcomes (all $r > 0.6$, all $p < 0.001$). Further, higher Ln HF power was associated with lower age ($r = -0.44$, $p < 0.001$), resting heart rate ($r = -0.47$, $p < 0.001$), systolic blood pressure ($r = -0.33$, $p = 0.008$), diastolic blood pressure ($r = -0.27$, $p = 0.031$), total cholesterol ($r =$ -

0.26, p = 0.038), LDL cholesterol (r = -0.26, p = 0.038), and total cholesterol to HDL ratio (r = -0.33, p = 0.008).

Outcomes

All outcomes are presented in Table 5.2.

Heart rate variability

No significant difference in the Ln HF power component of HRV was observed between groups over time (p = 0.912, η_p^2 = 0.000). Further, no group by time interactions were noted in any of the secondary HRV outcomes, including Ln LF power (p = 0.424, η_p^2 = 0.011), Ln LF:HF (p = 0.978, η_p^2 = 0.000), Ln total power (p = 0.755, η_p^2 = 0.002), pNN50 (p = 0.353, η_p^2 = 0.014), Ln SDNN (p = 0.948, η_p^2 = 0.000), Ln RMSSD (p = 0.942, η_p^2 = 0.000) and Ln Triangular Index (p = 0.486, η_p^2 = 0.008).

Haemodynamic outcomes

No differences between groups over time were noted for resting heart rate (p = 0.248, η_p^2 = 0.022), systolic blood pressure (p = 0.517, η_p^2 = 0.007), diastolic blood pressure (p = 0.769, η_p^2 = 0.001) or AIx (p = 0.294, η_p^2 = 0.022).

Haematological outcomes

No differences between groups over time were found in total cholesterol (p = 0.635, η_p^2 = 0.004), HDL (p = 0.886, η_p^2 = 0.000), total cholesterol to HDL ratio (p = 0.450, η_p^2 = 0.010), LDL (p = 0.412, η_p^2 = 0.011), triglycerides (p = 0.522, η_p^2 = 0.007), fasting blood glucose (p = 0.672, η_p^2 = 0.003) or Ln hsCRP (p = 0.430, η_p^2 = 0.010).

Anthropometric and body composition outcomes

No differences between groups over time were found in body weight (p = 0.618, η_p^2 = 0.004), BMI (p = 0.496, η_p^2 = 0.008) or waist circumference (p = 0.204, η_p^2 = 0.027). There were also no group by time interactions noted for body fat percentage (p = 0.231, η_p^2 = 0.024), fat mass (p = 0.714, η_p^2 = 0.002), lean body mass (p = 0.126, η_p^2 = 0.039), or fat free mass (p = 0.147, η_p^2 = 0.035). The data of six participants who did not fit comfortably within the scan region were calculated using the software estimate function.

Effect of adherence on adaptation

ANCOVAs indicated that higher attendance in the experimental group (i.e. number of classes) was associated with significant reductions in diastolic blood pressure (p = 0.039, η_p^2 = 0.154), body fat percentage (p = 0.001, η_p^2 = 0.379), fat mass (p = 0.003, η_p^2 = 0.294) and BMI (p = 0.05, η_p^2 = 0.139). Moreover, weak evidence of association was noted between higher attendance and reduced systolic blood pressure (p = 0.072, η_p^2 = 0.119), body weight (p = 0.062, η_p^2 = 0.128), waist circumference (p = 0.072, η_p^2 = 0.120) and HDL cholesterol (p = 0.052, η_p^2 = 0.137).

Table 5.2: Summary of between group changes on clinical outcomes

Outcome Measure	Yoga (n =29)		Control (n = 34)		Unadjusted Mean difference (95% CI)	p (between groups)	Effect Size (η_p^2)
	Week 0	Week 17	Week 0	Week 17			
Heart Rate Variability							
Ln HF power (absolute)	6.39 ± 1.30	6.27 ± 1.30	5.67 ± 1.46	5.76 ± 1.48	-0.503 (-1.203 – 0.196)	0.912	0.000
Ln LF power (absolute)	6.14 ± 1.17	5.93 ± 1.09	5.66 ± 1.10	5.44 ± 1.19	-0.488 (-1.063 – 0.088)	0.424	0.011
Ln LF:HF ratio	-0.244 ± 0.95	-0.337 ± 0.92	-0.002 ± 1.17	-0.213 ± 1.17	0.124 (-0.406 – 0.653)	0.978	0.000
Ln total power	7.52 ± 1.01	7.33 ± 1.05	7.02 ± 0.94	6.92 ± 1.06	-0.406 (-0.940 – 0.128)	0.755	0.002
pNN50	21.81 ± 21.35	21.46 ± 22.71	18.72 ± 20.74	21.80 ± 24.49	0.338 (-11.566 – 12.243)	0.353	0.014
Ln SDNN	3.99 ± 0.46	3.95 ± 0.48	3.74 ± 0.44	3.77 ± 0.50	-0.183 (-0.429 – 0.063)	0.948	0.000
Ln RMSSD	3.78 ± 0.65	3.80 ± 0.68	3.50 ± 0.68	3.61 ± 0.68	-0.188 (-0.531 – 0.156)	0.942	0.000
Ln Triangular Index	5.91 ± 0.45	5.92 ± 0.43	5.85 ± 0.48	5.83 ± 0.51	-0.098 (-0.333 – 0.138)	0.486	0.008
Haemodynamic measures							
Resting heart rate (bpm)	64.1 ± 8.0	62.9 ± 8.3	65.4 ± 9.1	62.2 ± 8.7	-0.784 (-5.084 – 3.516)	0.248	0.022
Systolic blood pressure (mmHg)	120.3 ± 11.1	119.1 ± 10.3	119.8 ± 9.1	119.6 ± 8.9	0.49 (-4.419 – 5.399)	0.517	0.007
Diastolic blood pressure (mmHg)	74.7 ± 7.9	73.5 ± 8.0	76.1 ± 6.4	74.3 ± 7.2	0.875 (-2.970 – 4.721)	0.769	0.001
Augmentation index (@75bpm)^	16.1 ± 9.8	16.2 ± 8.8	12.9 ± 13.1	13.5 ± 11.3	-2.678 (-7.842 – 2.487)	0.294	0.022
Haematological measures							
Total cholesterol (mmol/L)	5.15 ± 0.84	5.15 ± 0.69	5.03 ± 0.91	4.98 ± 1.11	-0.169 (-0.628 – 0.289)	0.635	0.004

HDL (mmol/L)	1.59 ± 0.52	1.53 ± 0.47	1.40 ± 0.38	1.37 ± 0.34	-0.157 (-0.369 – 0.055)	0.886	0.000
TC/HDL ratio	3.53 ± 1.24	3.65 ± 1.20	3.83 ± 1.25	3.84 ± 1.26	0.187 (-0.435 – 0.808)	0.450	0.010
LDL (mmol/L)^	2.94 ± 0.75	3.07 ± 0.71	3.03 ± 0.84	3.02 ± 1.01	-0.045 (-0.481 – 0.390)	0.412	0.011
Triglycerides (mmol/L)	1.27 ± 0.93	1.22 ± 0.64	1.28 ± 0.81	1.28 ± 0.65	0.065 (-0.260 – 0.391)	0.522	0.007
Fasting blood glucose (mmol/L)	5.01 ± 0.58	5.04 ± 0.57	4.94 ± 0.44	4.94 ± 0.52	-0.100 (-0.377 – 0.177)	0.672	0.003
Ln hsCRP	0.64 ± 1.35	0.51 ± 1.27	0.80 ± 1.23	0.78 ± 1.22	0.268 (-0.363 – 0.900)	0.430	0.010
Body Composition^							
Body weight (kg)	86.4 ± 21.2	86.2 ± 21.3	90.4 ± 21.0	91.3 ± 21.3	4.328 (-6.279 – 14.935)	0.618	0.004
Body mass index (kg/m^2)	29.9 ± 6.2	29.8 ± 6.2	30.9 ± 6.3	31.0 ± 6.3	1.186 (-1.977 – 4.349)	0.496	0.008
Waist circumference (cm)	93.9 ± 14.5	92.6 ± 14.7	95.3 ± 15.1	95.0 ± 14.1	2.399 (-4.898 – 9.696)	0.204	0.027
Fat mass (kg)	34.5 ± 14.5	34.4 ± 14.4	38.0 ± 14.0	37.5 ± 13.8	3.141 (-4.066 – 10.348)	0.714	0.002
Lean mass (kg)	48.8 ± 10.4	48.8 ±10.7	48.3 ± 11.0	48.9 ± 10.8	0.117 (-5.390 – 5.624)	0.126	0.039
Fat-free mass (kg)	51.7 ± 10.9	51.8 ± 11.2	51.4 ± 11.4	52.0 ± 10.9	0.150 (-5.575 – 5.876)	0.147	0.035
Body fat (%)	40.4 ± 9.3	40.4 ± 9.3	43.2 ± 8.7	42.6 ± 8.8	2.188 (-2.442 – 6.819)	0.231	0.024

^ = sample size differs to main data set. DXA data: yoga group n = 28. AIx: baseline yoga group n=22, baseline control group n=30, completion yoga group n=27. LDL: baseline yoga group n=28.

* = $p < 0.05$

Data reported as mean (standard deviation). Abbreviations: HF: high frequency; LF: low frequency; pNN50: percentage of absolute differences between successive normal RR intervals that exceed 50ms; SDNN: standard deviation of the normal-normal interval; RMSSD: root-mean-square the successive normal sinus RR interval difference; HDL: high-density lipoprotein; TC/HDL: ratio of total cholesterol to HDL; LDL: low-density lipoprotein; hsCRP: high sensitivity c-reactive protein.

5.5 Discussion

The present study investigated the effect of 16-weeks of Bikram yoga on the HF component of HRV, and secondary CVD risk factors in sedentary, stressed adults. Intention-to-treat analysis revealed that the Bikram yoga intervention did not significantly improve the HF power component of HRV or any other CVD risk factors investigated, contrary to our hypotheses. Attendance in the experimental group (n = 29) was low, averaging 27 classes, which is 56% of the minimum 48 classes required. Low attendance may have contributed to our null findings. Regression analyses revealed that higher attendance was associated with significant reductions in diastolic blood pressure, body fat percentage, fat mass, and BMI. Continued investigation into adherence to Bikram yoga interventions may reveal further information on the dose-response effect of Bikram yoga on CVD risk factors.

Our findings for HRV outcomes are supported by a recent systematic review (Posadzki et al., 2015), which concluded that current evidence cannot describe a definitive effect of chronic *hatha* yoga practice on measures of HRV, including HF component of HRV, LF component of HRV, LF:HF, total power, SDNN, and RMSSD. The HF component of HRV can be increased acutely by a reduced respiration rate, which likely contributed to the positive findings noted in some acute trials (Melville et al., 2012; Posadzki et al., 2015). The present study suggests that there is no chronic increase in vagal tone (relaxation response) in response to the intervention, however previous research suggests that Bikram and non-Bikram yoga interventions do reduce psychological stress (Chong et al., 2011; Hewett et al., 2011) and reduce cortisol reactivity to stress (Hopkins et al., 2016). Heart rate variability can also be increased from via exercise-induced adaptation of the cardiovascular system. Research to date indicates that Bikram yoga does not elicit a strong enough cardiovascular training load in sedentary, apparently healthy adults to improve maximal oxygen update (Hunter et al., 2013; Tracy & Hart, 2013). The null findings in the present study may be due to the lack of chronic adaptation of the cardiac muscle (i.e. increased stroke volume) required for adaptation in HRV despite past evidence for reduced psychological stress from Bikram yoga intervention. Preliminary data show that Bikram yoga elicits an average, in-session metabolic response equivalent to that of walking (Fritz et al., 2013; Pate & Buono, 2014) which may, in a higher risk, less fit population, lead to increased HRV via adaptation in cardiac muscle and stroke volume after a Bikram yoga intervention. Interestingly, a study examining integrated *hatha* yoga (ethical and spiritual components) versus *hatha* yoga (as exercise only) reports that only those in the integrated group experienced significant decreases in physiological measures of stress (i.e. salivary cortisol) (Smith et al., 2011). This finding suggests that the framework of *hatha* yoga RCTs, including the reasons for which participants initially register, may influence adaptations of physiological stress markers.

There was a null effect of Bikram yoga on secondary haemodynamic outcomes in the present study. Our findings in this cohort of normotensive adults (Table 5.2) support those of previous studies (controlled and uncontrolled), which report unchanged blood pressure and resting heart rate in normotensive adults after 8 weeks of Bikram or non-Bikram *hatha* yoga performed one to three sessions per week (Hewett et al., 2011; Hunter et al., 2013; Papp et al., 2013; Tracy & Hart, 2013). Interestingly, a cross-sectional study reported that resting blood pressure of long-term Bikram yoga practitioners (one year) was lower than the general United States population indicating that this practice may have a beneficial effect on haemodynamic health (Abel et al., 2012). Moreover, longer (five to six months) *hatha* yoga RCTs report significant improvements in blood pressure in coronary artery disease patients and pre-hypertensive individuals living with HIV infection (Cade et al., 2010; Nagarathna et al., 2012; Pal et al., 2011). A previous study in healthy young adults has also noted within group reductions in arterial stiffness measured at the carotid artery after eight weeks of Bikram yoga intervention (Hunter et al., 2013). The significant association between adherence and diastolic blood pressure (p = 0.039, η_p^2 = 0.154), and weaker evidence of association in systolic blood pressure (p = 0.072, η_p^2 = 0.119) in the present study indicate that there may be a dose-response effect for blood pressure changes in relation to Bikram yoga. Considering both the relationship between adherence and adaptation, and the potential vascular benefits of heat therapy shown in several studies (Brunt et al., 2016; Imamura et al., 2001; Laukkanen et al., 2015), an RCT in a pre-hypertensive or hypertensive cohort, with adequate adherence to intervention, may elicit Bikram yoga intervention-related changes in systolic and diastolic blood pressure.

No significant changes were found for haematological CVD risk factors. An 8-week, uncontrolled Bikram trial also reported no change to fasting blood glucose in adults, although improvements in glucose tolerance were noted in obese adults (Hunter et al., 2013). Contrary to the present results, however, an uncontrolled 8-week Bikram yoga trial reported significant within group decreases in total cholesterol and LDL in older adults, and significant within group decreases in total cholesterol and HDL in young adults (Hunter et al., 2013). The current trial also provides weak evidence for reduced HDL with higher attendance (p = 0.052, η_p^2 = 0.137). This is an unexpected HDL change in response to exercise, however, HDL levels were 1.53 ± 0.47 mmol/L at completion, which is still well above recommended levels for a healthy blood lipid profile (>1.0 mmol/L). The same 8-week study also reports that plasma insulin and insulin resistance via homeostatic model assessment (HOMA-IR) improved significantly (within group) in older adults (Hunter et al., 2013). Further, RCTs longer than eight weeks suggest that *hatha* yoga can improve blood lipids, blood glucose and haemoglobin A1c in unhealthy populations (Nagarathna et al., 2012; Pal et al., 2011; Sharma & Knowlden, 2012). There was no adaptation in hsCRP in the present study. This finding is contrary to a 4-week *hatha* yoga RCT in apparently healthy, male railway engine drivers, and an 8-week *hatha* yoga RCT in heart failure patients (Pullen et al., 2010; Shete et al., 2012). Although adherence did not appear to be associated with blood measure outcomes, it is possible that a higher risk cohort with elevated CVD risk factor blood measures at baseline would experience significant reductions in response to an appropriate volume of Bikram yoga training.

There was no significant adaptation of body weight, body composition, waist circumference or BMI in the present study. An RCT reported a trend in reduced body fat after 8-weeks of Bikram yoga, although no diet data was recorded during that 8-week trial (Tracy & Hart, 2013). Preliminary energy expenditure data from two studies indicates that Bikram yoga elicits a higher metabolic equivalent (MET) energy expenditure level compared to other forms of *hatha* yoga, and that it can be compared energetically to walking up to 3.7 METS (Clay et al., 2005; Fritz et al., 2013; Pate & Buono, 2014). Both studies include data from experienced practitioners, who may have higher exertion and energy expenditure rates during class than that of the current, less experienced, less active practitioners. Yoga has been associated with attenuated weight gain in healthy adults over a 10-year period (Kristal et al., 2005). In the current trial, more regular attendance was associated with reductions in body fat percentage (p = 0.001, η_p^2 = 0.379), fat mass (p = 0.003, η_p^2 = 0.294) and BMI (p = 0.05, η_p^2 = 0.139). These data suggest that Bikram yoga may serve as an effective weight maintenance tool and, with an appropriate training volume, a tool for body fat reduction.

A major strength of this study was its rigorous RCT design (Moher et al., 2001), which is currently lacking in the investigation of Bikram yoga. A major limitation to the study was low attendance with participants attending on average 1.7 classes per week compared to the minimum requirement of three classes per week. Poor attendance could be due to the duration of the 16-week trial or the time demand of the 90-minute classes. Another limitation to the study is that the cohort may have been too low-risk to see adaptation in certain measures including blood pressure, blood lipids and hsCRP. Further, data was collected without considering the timing in relation to menstrual cycle. In this predominantly female cohort, that oversight may have affected some outcome measures. Some participants experienced discomfort relating to pre-existing musculoskeletal conditions during the study, which would not be uncommon when starting an exercise program after being sedentary for some period. The intervention may have exacerbated this discomfort for some participants due to the group exercise setting. To reduce intervention-related discomfort, future study design could include one pre-intervention yoga class to better familiarize participants with the protocol and to ensure that they are given specific, individual feedback for performing the *asanas* in a way that minimizes discomfort.

Future research should explore the effects of Bikram yoga in unhealthy populations to better examine the effects of this form of heated *hatha* yoga on CVD risk factors. However, in light of the association of adherence on the outcomes demonstrated in this study, more acute and intervention-based research is required to determine a suitable, minimum volume of Bikram yoga in order to encourage an adequate level of adherence that elicits physiological change in various outcomes. Furthermore, cross-sectional and longitudinal data on long term practitioners could lend valuable insight into the characteristics of a Bikram yoga practitioner, including motivation to start and continue a Bikram yoga practice, as well as perceived barriers to continue. Determining how to better facilitate adherence to Bikram yoga interventions is an important consideration moving forward, especially considering that a stressed cohort with little yoga experience potentially faces more barriers to initiating a yoga practice than an individual initiating a yoga practice independent of the RCT framework.

Conclusion

In summary, a 16-week Bikram yoga program did not increase the HF power component of HRV or any other CVD risk factors investigated. Low adherence likely contributed to the null effects. Regression analyses indicated that higher attendance was significantly associated with reductions in diastolic blood pressure, body fat, fat mass and BMI, and weaker associations were noted in systolic blood pressure, body weight and waist circumference. Future studies are required to address barriers to adherence and elucidate the dose-response effects of Bikram yoga practice.

Chapter 6

Effect Of A 16-Week Bikram Yoga Program On Perceived Stress, Self-Efficacy And Health-Related Quality Of Life In Stressed And Sedentary Adults: A Randomised Controlled Trial

This chapter is *in press* with the Journal of Science and Medicine in Sport:

Hewett, Z.L., Pumpa, K.L., Smith, C.A., Fahey, P.P., Cheema, B.S. (2017). Effect of a 16-week Bikram yoga program on perceived stress, self-efficacy and health-related quality of life in stressed and sedentary adults: A randomised controlled trial.

6.1 Abstract

Objectives: The purpose of this study was to investigate the effect of 16 weeks of Bikram yoga on perceived stress, self-efficacy and health related quality of life (HRQoL) in sedentary, stressed adults.

Methods: This was a 16 week, parallel-arm, randomised controlled trial. Physically inactive and mildly stressed adults (37.2±10.8 years) were randomised to Bikram yoga (three to five classes per week) or control (no treatment) group for 16 weeks. Outcome measures, collected via self-report, included perceived stress, general self-efficacy, exercise self-efficacy, and HRQoL. Outcomes were assessed at baseline, midpoint and completion.

Results: Individuals were randomised to the experimental (n = 29) or control group (n = 34). Average attendance in the experimental group was 27 ± 18 classes. Repeated measure analyses of variance (intention-to-treat) demonstrated significantly improved perceived stress ($p = 0.003$, partial $\eta^2 = 0.109$), general self-efficacy ($p = 0.034$, partial $\eta^2 = 0.056$), exercise self-efficacy ($p = 0.003$, partial $\eta^2 = 0.099$), and the general health ($p = 0.034$, partial $\eta^2 = 0.058$) and energy/fatigue ($p = 0.019$, partial $\eta^2 = 0.066$) domains of HRQoL in the experimental group versus the control group. Attendance was significantly associated with reduced perceived stress, increased exercise self-efficacy and increases in several domains of HRQoL.

Conclusions: 16 weeks of Bikram yoga significantly improved perceived stress, general- and exercise self-efficacy and HRQoL in sedentary, stressed adults. Future research should consider ways to optimise adherence, and should investigate effects of Bikram yoga intervention in other populations at risk for stress-related illness.

6.2 Introduction

Psychological stress arises when an individual perceives environmental demands to exceed his or her adaptive capacity. Stress can increase the risk of developing chronic conditions including cardiovascular disease (CVD) and metabolic disease (Chrousos, 2000). In 2015, 35% of Australians experienced significant levels of distress (APS). Further, two thirds of Australians believe that stress impacts physical and mental health status, yet only half of these people seek help from medical professionals, family or friends (APS).

Exercise is one of the more effective techniques to reduce psychological stress (APS, 2015), yet stress has been shown to contribute to lower engagement in exercise, particularly in sedentary individuals (Stults-Kolehmainen & Sinha, 2014). Those without established exercise habits tend to decrease physical activity in response to stress compared to habitual exercisers, who are more likely to use exercise to manage stress (Stults-Kolehmainen & Sinha, 2014). High stress is also associated with low self-efficacy (Yu et al., 2015), one's belief in his or her abilities to overcome barriers to achieve goals of importance, an attribute which contributes to exercise uptake and adherence (Sherwood & Jeffery, 2000). Low self-efficacy may also mediate other adverse psychological effects that arise from stress including depression (Sawatzky et al., 2012). The inability to manage stress has been associated with lower health-related quality of life (HRQoL) in apparently healthy and chronically diseased cohorts (Faul et al., 2010; Marshall et al., 2008).

Bikram yoga is a specific system of *hatha* (physical) yoga characterised by a 90-minute, unchanging sequence of *asanas* (postures) performed in a heated environment (40.6°C, 40% humidity) (Choudhury, 2007). This form of *hatha* yoga purports to induce significant health benefits, including improvements in physical fitness and some physiological and psychological parameters, however, only three investigations of Bikram yoga to date have implemented an RCT design (Hewett et al., 2015; Hewett et al., 2017;

Hopkins et al., 2016). A systematic review reports that non-Bikram yoga (predominantly *hatha*) may improve mood and mediate the stress response (Pascoe & Bauer, 2015). Further, heat therapies including sauna bathing and sweat-practices are used across cultures to promote well-being, induce relaxation and improve hyperactivity, mood and stress (Eason et al., 2009).

There is preliminary evidence that eight weeks of Bikram yoga practice can improve perceived stress in apparently healthy adults (Hewett et al., 2015). However, no RCT to date has specifically investigated the effect of Bikram yoga on perceived stress, or associated factors, such as self-efficacy and HRQoL, in sedentary and stressed adults (Hewett et al., 2015). Therefore, we hypothesised that participants randomised to 16-weeks of Bikram yoga intervention would significantly decrease perceived stress, and increase general- and exercise self-efficacy and all domains of HRQoL compared to participants randomised to a no-treatment control group.

6.3 Methods

This 16-week, parallel-arm RCT compared the outcomes of participants randomised to an experimental Bikram yoga group or a no-treatment control group. Outcomes were collected at baseline (week zero), midpoint (week eight) and following the intervention period (week 17). Ethics approval was granted by the University Human Research Ethics Committee, which conforms to the requirements stipulated in the Declaration of Helsinki. Written informed consent was obtained from all participants.

Eligibility criteria: (1) Adult (≥18 years); (2) sedentary (i.e. <150min of moderate-intensity exercise per week for more than six months); (3) a score >14 on the stress component of the Depression, Anxiety and Stress Scale (DASS-21) (Lovibond & Lovibond, 1995) indicating mild stress; (4) no diagnosed chronic diseases; 5) no acute or chronic medical condition that would make Bikram yoga potentially hazardous (e.g. pregnancy) or outcomes difficult to assess; (6) able to attend three to five Bikram yoga classes per week for 16 weeks; (7) cognition and English language sufficient to understand research procedures and provide informed consent; (8) no participation in Bikram yoga in the past six months.

Participants were recruited, screened and enrolled between August 2014 and September 2015. Details of recruitment, screening and enrolment are reported elsewhere (Hewett et al., 2017). One trained researcher collected all baseline and completion outcome measures (week zero and 17) at the local university. Midpoint measures (week eight) were delivered via email and returned via email or in person. Data collection was completed in January 2016.

The sample size for this study is based on sample size calculations for a primary outcome reported in another paper using the same cohort, as previously reported (Hewett et al., 2017). Participants were randomised via a computer-generated list stratified by sex and age (< 50yr; ≥ 50yr). An investigator not involved in testing or delivery of the intervention prepared the randomisation assignments. Group assignments were delivered to participants in person in sealed envelopes upon completion of baseline testing.

Participants in the experimental group engaged in 16-weeks of Bikram yoga classes at either of two affiliated Bikram yoga studios. Participants were instructed to attend between three to five regularly scheduled classes per week. Certified Bikram yoga teachers instructed all classes using a set instructional dialogue. Each 90-minute class was held in a temperature-controlled room (40.6°C, 40% humidity). The class opened with a deep breathing exercise, and continued with 45-50 minutes of standing *asanas* and 40-45 minutes of floor-based *asanas*, including a quick, forceful breathing exercise to finish (Choudhury, 2007). All but the last *asana* (spine-twisting) were performed twice. *Savasana* (restorative, relaxation posture) was performed between *asanas* throughout the floor series and at the end of class (Choudhury, 2007).

Participants in the control group were instructed to maintain current lifestyle practices and were not provided any information or instructions about Bikram yoga practice. However, participants were informed during recruitment and screening that control group participants would be provided a complimentary 10-class pass at one of the participating studios upon completion of the trial.

All instruments evaluating perceived stress, general- and exercise self-efficacy and HRQoL we self-administered by participants in a quiet room. The 10-item Perceived Stress Scale (PSS) has been widely used and is a valid and reliable tool (internal consistency, i.e. Cronbach's $\alpha \geq 0.84$) to assess perceived stress in adults (Cohen, 1988). Higher scores reflect higher stress. The 10-item General Self-Efficacy (GSE) scale has been shown to be a reliable construct (internal consistency, i.e. Cronbach's $\alpha =$ 0.75-0.91) to measure general self-efficacy across different cultures (Schwarzer et al., 1999). A 5-item questionnaire was used to assess exercise self-efficacy (internal consistency, i.e. Cronbach's $\alpha = 0.88$) (Schwarzer & Renner). Higher scores on both scales reflect higher self-efficacy. General health status and quality of life were assessed by the *RAND 36-Item Health Survey 1.0* (SF36), a measure that assesses eight domains of quality of life: physical functioning, bodily pain, role limitations due to physical health problems (physical role limitations), role limitations due to emotional problems (emotional role limitations), emotional well-being, social functioning, energy/fatigue, and general health. The SF36 is reliable, has construct validity and the domains have been shown to have acceptable internal consistency (Cronbach's $\alpha > 0.85$) in an apparently healthy population (Brazier et al., 1992).

Weekly status checks administered via phone, email or in person were used to check for major lifestyle changes and adverse events throughout the intervention period.

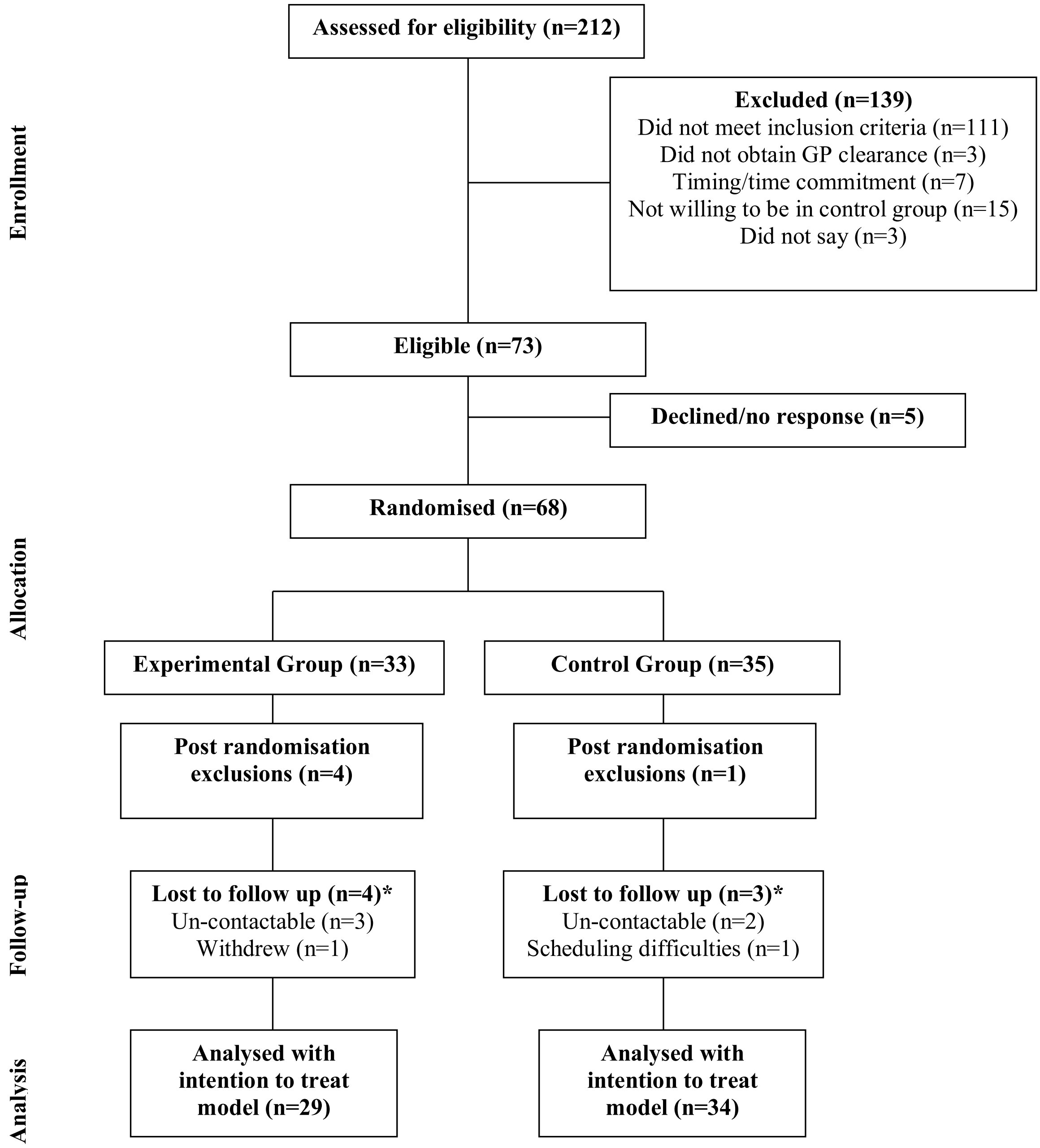
Participants who experienced an adverse event were advised to visit a qualified health care practitioner for assessment and treatment. Attendance in the experimental group was recorded electronically upon arrival at each respective studio via an online booking system managed by the staff member at reception. Attendance was reported as total number of sessions completed.

Primary analysis was undertaken using intention-to-treat including all eligible participants regardless of dropout or level of adherence. Missing data at week 17 was imputed carrying the last observation forward. Missing data at week 8 was imputed carrying the last observation backward. Outcomes data is presented as the mean ± standard deviation (SD) with effect size (partial eta-squared) and 95% confidence intervals (CI). Baseline characteristics were compared using t-tests and chi square tests. Intervention effects on outcome measures (group x time) were examined via repeated measures analysis of variance or covariance (ANOVA or ANCOVA). Significance was interpreted using the Greenhouse-Geisser p-value, and post hoc ANCOVA was used to interpret statistically significant repeated measures ANOVA results, comparing between group changes from week zero to week eight and from week eight to week 17. Pearson's correlation coefficients (r) were used to examine baseline associations between all outcomes and descriptive variables, with p-values reported for the hypothesis testing that the correlation was equal to zero. Supplementary analyses of the effect of attendance on outcomes was conducted using the same repeated measures ANOVA and ANCOVA methods. P-values less than 0.05 were considered statistically significant. Analyses were conducted using SPSS (IBM©, Version 23).

6.4 Results

The flow of participants is presented in Figure 6.1. Four participants in the yoga group and one participant from the control group were excluded from analysis post-randomisation after re-calculation of the DASS-21 stress scores (inclusion criterion score not met).

Figure 6.1 Flow of Participants



*Baseline data carried forward for three participants in each group lost to follow-up for intention-to-treat analysis.

Baseline descriptive characteristics are presented in Table 6.1. No significant differences were detected between groups at baseline in any of the descriptive characteristics (all $p > 0.05$). Participants ranged from 19 to 64 years of age and the majority of the cohort (87%) was under 50 years of age (55/63). The average DASS-21 stress score for the total cohort indicated a moderate level of stress (23.8 ± 6.0).

Table 6.1 Baseline Characteristics

Characteristic	Total cohort (n = 63)	Yoga group (n = 29)	Control group (n= 34)
Age (y)	37.2 ±10.8	38.2 ± 10.1	36.3 ± 11.4
Women (n; %)	50; 79%	23; 79%	27; 79%
Sedentary occupation (n; %)	57; 90%	26; 90%	31; 91%
Body weight (kg)	88.5 ± 21.0	86.4 ± 21.2	90.4 ± 21.0
Body mass index (BMI) (kg/m^2)	30.5 ± 6.2	29.9 ± 6.2	30.9 ± 6.3
Obese (BMI ≥30) (n; %)	27; 43%	11; 38%	16; 47%
Waist circumference (cm)	94.7 ± 14.7	93.9 ± 14.5	95.3 ± 15.1
Stress score (DASS-21)	23.8 ± 6.0	23.3 ± 6.0	24.3 ± 6.1
Depression score (DASS-21)	14.7 ± 10.3	15.2 ± 10.7	14.2 ± 10.1
Anxiety score (DASS-21)	10.2 ± 7.2	9.2 ± 6.6	11.1 ± 7.6
Current smoker or quit in last 6 months (n; %)	3; 5%	1; 3%	2; 6%
<5 previous Bikram yoga classes	57; 90%	25; 86%	32; 94%

Continuous data presented as mean ± standard deviation
Abbreviations: DASS-21 = 21-item Depression-Anxiety-Stress-Scale.
Depression: 0 – 9 = normal, 10 – 13 = mild, 14 – 20 = moderate, 21 – 27 = severe, 28+ = extremely severe
Anxiety: 0 – 7 = normal, 8 – 9 = mild, 10 – 14 = moderate, 15 – 19 = severe, 20+ = extremely severe
Stress: 0 – 14 = normal, 15 – 18 = mild, 19 – 25 = moderate, 26 – 33 = severe, 34+ = extremely severe

The experimental group attended 27 ± 18 (range: 4 to 79) of a maximum 80 classes. Nine participants attended >80% of the minimum required three classes per week (i.e. >38 of 48 classes). Ten participants attended a total of 16 or fewer classes (i.e. ≤1 class per week). Three control group participants engaged in structured aerobic and/or strength training programs during the intervention period. Six participants in the experimental group experienced exacerbation of pre-existing conditions during the trial (i.e. back pain, foot pain, knee pain, calf pain, psychological discomfort). All six participants were advised to consult their general practitioner. Three of these participants discontinued the intervention and three continued attending some classes when they could, with modifications to *asanas* if needed. One additional participant discontinued the intervention after sustaining a non-intervention related ankle sprain.

At baseline (n = 63), higher perceived stress was associated with lower general (r = -0.48, $p < 0.001$) and exercise self-efficacy (r = -0.41, p = 0.001), and also with lower HRQoL domain scores: physical role limitations (r = -0.44, $p < 0.001$), emotional role limitations (r = -0.62, $p < 0.001$), energy/fatigue (r = -0.58, $p < 0.001$), emotional well-being (r = -0.70, $p < 0.001$), social functioning (r = -0.53, $p < 0.001$) and general health (r = -0.31, p = 0.014). Older age was associated with higher general self-efficacy (r = 0.28, p = 0.027) and lower physical functioning (r = -0.36, p = 0.003).

All changes over time are presented in Table 6.2. The experimental group significantly reduced perceived stress and increased both general self-efficacy and exercise self-efficacy compared to control group over time. The general health and energy/fatigue domains of HRQoL significantly increased in the experimental group versus the control group over time. No significant interaction effects were found for the other HRQoL outcomes.

Post hoc ANCOVAs revealed a significant decrease in perceived stress (p = 0.001, η_p^2 = 0.173), increase in general (p = 0.018, η_p^2 = 0.09) and exercise self-efficacy (p = 0.001, η_p^2 = 0.173), and increase in general health (p = 0.015, η_p^2 = 0.095) and energy/fatigue (p = 0.006, η_p^2 = 0.117) at week 8 in the experimental versus control group, controlling for baseline. Exercise self-efficacy improved further at week 16 controlling for week 8 (p = 0.015, η_p^2 = 0.095).

Supplementary analysis using ANCOVAs indicated that higher attendance was associated with a larger reduction in perceived stress (p = 0.03, η_p^2 = 0.169) and larger increase in exercise self-efficacy (p = 0.002, η_p^2 = 0.308), but not with general self-efficacy (p = 0.518, partial η^2 = 0.007). Higher attendance was also associated with larger increases in several HRQoL domains: energy/fatigue (p = 0.022, η_p^2 = 0.187), emotional well-being (p = 0.022, η_p^2 = 0.187) and general health (p = 0.003, η_p^2 = 0.295). Weak evidence of association was noted in the physical functioning domain of HRQoL (p = 0.061, η_p^2 = 0.129).

Table 6.2: Summary of interaction effects between time and group on clinical outcomes (intention to treat)

Outcome Measure	Yoga (n =29)			Control (n = 34)			p (interaction effects)	Effect Size (η_p^2)
	Week 0	Week 8	Week 17	Week 0	Week 8	Week 17		
Perceived stress scale	20.7 ± 4.7	15.1 ± 6.3*	12.9 ± 7.6	21.3 ± 5.0	20.2 ± 5.4	19.1 ± 6.6	0.003	0.109
General self-efficacy	29.5 ± 4.4	32.3 ± 4.2*	32.6 ± 4.1	29.3 ± 4.6	30.1 ± 5.1	30.4 ± 4.6	0.034	0.056
Exercise self-efficacy	12.8 ± 4.1	14.3 ± 3.2*	14.9 ± 3.6**	11.8 ± 3.3	11.1 ± 3.6	11.1 ± 3.1	0.003	0.099
<u>SF-36</u>								
Physical functioning	82.6 ± 19.5	89.1 ± 19.0	89.1 ± 19.6	81.6 ± 15.6	82.4 ± 18.7	83.2 ± 18.5	0.140	0.032
Social functioning	67.7 ± 26.0	82.8 ± 21.0	84.1 ± 23.4	68.4 ± 22.0	69.9 ± 22.8	72.4 ± 23.6	0.086	0.040
Emotional wellbeing	63.4 ± 15.8	74.2 ± 15.9	76.6 ± 17.9	58.5 ± 15.8	62.5 ± 12.7	63.1 ± 16.9	0.083	0.042
Energy/fatigue	37.9 ± 16.3	51.4 ± 16.0*	54.5 ± 18.0	37.9 ± 19.8	41.6 ± 15.9	43.5 ± 17.9	0.019	0.066
Bodily Pain	70.7 ± 17.3	67.0 ± 20.9	79.1 ± 20.2	74.8 ± 18.3	63.5 ± 19.3	75.1 ± 17.2	0.161	0.030
Role limitations – physical	78.5 ± 30.4	84.5 ± 33.7	86.2 ± 28.0	73.5 ± 34.2	72.9 ± 37.1	73.5 ± 40.3	0.679	0.006
Role limitations - emotional	54.0 ± 33.8	75.9 ± 36.6	79.3 ± 37.2	39.2 ± 37.1	52.9 ± 41.1	47.1 ± 41.1	0.217	0.025
General health	50.5 ± 18.9	62.9 ± 19.0*	65.5 ± 20.9	47.2 ± 18.3	51.2 ± 21.1	54.3 ± 20.2	0.034	0.058

Data reported as mean ± standard deviation.
Abbreviation: SF-36; 36-Item Short Form Health Survey.
* = $p < 0.05$. Significant difference between groups at week 8, revealed by post hoc ANCOVA, controlling for baseline
** = $p < 0.05$. Significant difference between groups at week 17, revealed by post hoc ANCOVA, controlling for week 8

6.5 Discussion

This study investigated the effect of a 16-week Bikram yoga intervention on psychological health in stressed and sedentary adults. The experimental group significantly reduced perceived stress, and increased general and exercise self-efficacy versus the control group, congruent with our hypotheses. The experimental group also significantly improved two domains of HRQoL, general health and energy/fatigue. Higher attendance to Bikram yoga was associated with a larger reduction in perceived stress and larger increase in exercise self-efficacy and several domains of HRQoL.

The reduction of perceived stress within the first eight weeks in the present study is consistent with previous research (Hewett et al., 2015). Two specific components of Bikram yoga that may contribute to reductions of perceived stress include the mind-body nature of *hatha* yoga practice in general (i.e. a focus on *asanas,* breathing and relaxation/meditation) and the environmental conditions (i.e. 40.6°C, 40% humidity). *Hatha* yoga interventions (Pascoe & Bauer, 2015) and heated environments (Eason et al., 2009) have been shown to independently exert a positive effect on perceived stress, and hence an intervention that combines these elements (i.e. Bikram yoga) is likely to be therapeutic. The effect of Bikram yoga on perceived stress may also be associated with physiological changes that lower disease risk. For example, Bikram yoga twice per week for eight weeks has been shown to reduce salivary cortisol, a physiological marker of stress in stressed, emotional eaters (Hopkins et al., 2016). Emotional eating is an example of a harmful stress-management technique that can compound metabolic disease and CVD risk (Dallman, 2010). Given the link between psychological stress and CVD (Chrousos, 2000), deeper inquiry into the effect of Bikram yoga on stress reduction and stress management techniques, including coping strategies, should be extended to populations more significantly affected by stress, for example, posttraumatic stress disorder.

Increased general and exercise self-efficacy are novel findings of Bikram yoga practice. An RCT investigating 10 weeks of non-Bikram *hatha* yoga versus no treatment reported a significant improvement in exercise self-efficacy by week five in those receiving yoga (Bryan et al., 2012). Studies have also reported improvements in non-exercise domains of self-efficacy following non-Bikram *hatha* yoga intervention (Sherman et al., 2013; Sun et al., 2010). The heated environment may increase the intensity and challenge of the yoga practice regardless of individual level of experience and exertion, however this is speculative and requires further investigation. Repeatedly enduring the environment may foster a sense of accomplishment and control (Eason et al., 2009), potentially leading to enhanced exercise self-efficacy (Lox et al., 2003). Self-efficacy has also been shown to mediate the positive effects of *hatha* yoga on health outcomes in other populations (Sawatzky et al., 2012; Sherman et al., 2013). Future research should investigate the effect of Bikram yoga on populations suffering from mental health conditions associated with low self-efficacy, such as depression (Philip et al., 2013). Further, *hatha* yoga may increase adherence to non-yoga-based exercise in previously sedentary adults (Bryan et al., 2012). Future trials should consider an extended follow up period to examine the ongoing effects of increasing self-efficacy via Bikram yoga on increasing general physical activity, which is crucial for prevention of chronic disease.

Two domains of HRQoL, general health and energy/fatigue, significantly improved in the experimental group. Previous research has not investigated the effect of Bikram yoga on the HRQoL outcomes measured in the current study. However, one uncontrolled Bikram yoga trial reported significantly improved life satisfaction in 22 apparently healthy adults (Bikram yoga experience averaging 1.79 years) after completing at least 48 classes within 60 days (Rissell et al., 2014). Previous trials report improvements in the general health and energy/fatigue domains of HRQoL after non-Bikram *hatha* yoga intervention in healthy adults and chronically diseased populations (Lakkireddy et al., 2013; Lau et al., 2015). Further, general health and energy/fatigue scores in the current trial (mean age 37 years) were at or below average compared to Australian population sample scores for adults aged 35-44 years (Hawthorne et al., 2007). Contrary to our hypotheses, the remaining HRQoL domains did not significantly change between groups. This lack of findings may be attributable to this specific cohort, which scored above average in these domains compared to Australian population sample scores (Hawthorne et al., 2007).

In addition to the positive findings demonstrated by this study, more frequent class attendance in the experimental group was associated with significantly reduced perceived stress, increased exercise self-efficacy, and improvements in emotional well-being, general health and energy/fatigue. These findings indicate a dose-response effect in these outcomes. Future research should investigate the minimum dose of Bikram yoga required for the adaptation of the outcomes investigated in this trial.

A major strength of this study was its RCT design, which is currently lacking in this area of research (Hewett et al., 2015). Two major limitations were that: (1) the data collector was not blinded to group allocation, and (2) self-report responses may have been influenced by participant and/or investigator expectations for improvement (Boot et al., 2013). Future research should use an active control group and measure participant expectancy prior to intervention, as well as involve blind data collectors to mitigate potential placebo effects. An additional limitation was that the range of prescribed classes may have increased the variability of treatment. Low adherence and exacerbation of pre-existing conditions also contributed to increased variability of treatment. Future research should investigate the dose-response effect of Bikram yoga on psychological outcomes, and should investigate factors that contribute to improving adherence in sedentary and stressed adults. Specific pre-intervention preparation may be warranted to assess individual limitations and barriers to enhance adherence to Bikram yoga.

Conclusions

In summary, a 16-week Bikram yoga intervention reduced perceived stress, increased general and exercise self-efficacy and improved two domains of HRQoL. Higher attendance was associated with a reduction in perceived stress, and, increases in exercise self-efficacy and the energy/fatigue, emotional well-being and general health domains of HRQoL. The dose-response effect of Bikram yoga should be investigated further. Future research should also consider ways to optimise adherence and investigate the effects of Bikram yoga intervention in other populations with high levels of stress.

Practical implications

- Bikram yoga may effectively reduce psychological stress in stressed and sedentary adults.
- Bikram yoga may be an effective intervention to improve general and exercise self-efficacy and HRQoL.
- Higher class attendance may be associated with greater improvements in psychological health.

Chapter 7

Predictors Of And Barriers To Adherence In A 16-Week Randomised Controlled Trial Of Bikram Yoga In Stressed And Sedentary Adults

This chapter has been submitted to BMC Complementary and Alternative Medicine:

Hewett, Z.L., Pumpa, K.L., Smith, C.A., Fahey, P.P., Cheema, B.S. (2017) Predictors of and barriers to adherence in a 16-week randomised controlled trial of Bikram yoga in stressed and sedentary adults.

7.1 Abstract

Background: Bikram yoga may enhance health outcomes in healthy adults and those at risk for chronic disease, however, challenges remain in achieving optimal adherence to this practice. This study investigated factors influencing adherence to a 16-week Bikram yoga intervention in stressed and sedentary adults.

Methods: Experimental group participants (n = 29) were instructed to attend three to five Bikram yoga classes weekly for 16 weeks. Baseline demographics, behaviours and health measures were investigated as predictors of adherence. Barriers were assessed via documentation of adverse events, and exit survey responses.

Results: Participants (38.2 ± 10.1 years) were predominantly overweight-obese (83%), female (79%), and attended 27 ± 18 classes. Higher adherence was associated with older age, less pain, fewer physical limitations, poorer blood lipid profile, and higher heart rate variability (HRV; total power). In multi-variable analysis, three variables: age ($\beta = 0.492$, $p = 0.006$), HRV ($\beta = 0.413$, $p = 0.021$) and pain ($\beta = 0.329$, $p = 0.048$) remained predictors of adherence. Difficulty committing to the trial, lack of enjoyment and adverse events were barriers to adherence.

Conclusions: These findings should be considered in the development of future Bikram yoga trials to facilitate higher levels of adherence, which may enhance health outcomes and inform community practice. Future trials should investigate and address additional barriers and facilitators of Bikram yoga practice.

7.2 Introduction

Bikram yoga is a standardised style of *hatha* (physical) yoga characterised by an unchanging sequence of *asanas* (postures), heated environment and instructional dialogue (Choudhury, 2007). Studies have demonstrated that eight weeks of Bikram yoga practice can enhance health outcomes in apparently healthy adults and those at risk for chronic disease (Hewett et al., 2015; Hopkins et al., 2016; Medina et al., 2015). Bikram yoga consists of beginner-level *asanas,* making it suitable for virtually all fitness levels. However, despite its applicability and potential benefits, challenges remain in successfully applying this intervention in adults who are sedentary.

Conventional forms of exercise exert a dose-response effect such that more frequent and/or vigorous exercise contributes to higher levels of health status (ACSM, 2010; Warburton et al., 2006). Dose-response effects have been noted in studies of Bikram yoga. A recent 16-week randomised controlled trial (RCT) reported that higher adherence to Bikram yoga intervention in a cohort of stressed and sedentary adults was associated with significant reductions in body fat percentage (p = 0.001), fat mass (p = 0.003), diastolic blood pressure (p = 0.039), and body mass index (BMI) (p = 0.05) (Hewett et al., 2017). Higher adherence in this trial was also associated with favourable psychological adaptations, including improvements in exercise self-efficacy (p = 0.002), perceived stress (p = 0.03), and several domains of health-related quality of life (HRQoL) ($p \leq 0.022$) (see chapter six). Notably, class attendance averaged 54% of the minimum prescribed classes and only four participants (14%) met or exceeded the minimum requirement of 48 classes over 16 weeks. Other studies of Bikram yoga (eight weeks) have either not reported on adherence (Hewett et al., 2015; Hunter et al., 2013; Hunter et al., 2017; Hunter et al., 2016), or have reported that attendance varies, ranging from 60% (Hopkins et al., 2016; Medina et al., 2015) to 94% (Hart & Tracy, 2008; Tracy & Hart, 2013). However, none of these studies provided an *a* *priori* definition of how attendance was computed indicating a lack of consistency in reporting attendance across trials (Hewett et al., 2015; Hopkins et al., 2016; Medina et al., 2015).

To our knowledge, only one study has reported on predictors of adherence to Bikram yoga. In a study of women with body image concerns, higher tolerance to distress was positively associated with adherence to Bikram yoga practice in those who were overweight (p = 0.009), while a negative relationship between these factors was noted in those who were obese (p = 0.007) (Baird et al., 2016). Obesity was therefore interpreted as a potential barrier to Bikram yoga practice in this study (Baird et al., 2016). Additional characteristics that have been reported as barriers to conventional exercise, include low self-efficacy, high levels of psychological stress, time constraints, and lack of readiness to change behaviour (Sherwood & Jeffery, 2000), may also affect participation in *hatha* yoga (Cheung et al., 2015; Dayananda et al., 2014). For example, 'family commitments and occupational commitments', have acted as significant barriers to yoga practice in yoga instructor graduates (Dayananda et al., 2014). 'Health problems', 'pain' and 'being too busy' have also been noted as barriers to *hatha* yoga in a study of older women with osteoarthritis (Cheung et al., 2015).

Bikram yoga can induce positive health-related adaptations (Hewett et al., 2015; Hopkins et al., 2016), however, there has been limited investigation of factors that contribute to adherence to a Bikram yoga intervention. Such investigation is required to enhance the uptake of Bikram yoga in those who could benefit significantly from it. Therefore, the purpose of the present study was to investigate factors that predicted and acted as perceived barriers to adherence to a 16-week Bikram yoga intervention in a cohort of stressed and sedentary adults.

7.3 Methods

Study design

The data presented in this study were collected during a 16-week RCT. The study methodology adhered to CONSORT guidelines (Moher et al., 2001) and is detailed elsewhere (Hewett et al., 2017). Briefly, eligible participants were randomised to a Bikram yoga experimental group or no-treatment control group. Outcomes were assessed at baseline, eight weeks post-randomisation (questionnaires only), and at completion of the trial. Two trained researchers collected all outcome measures, except for haematological measures, which were collected and analysed by an independent blood collection centre (blinded). The Western Sydney University (H10549) and University of Canberra Human Research Ethics Committees (H10549-14/009174) approved all procedures, and written informed consent was obtained from all participants.

Participants and recruitment

Eligibility criteria: (1) Adult (≥18 years); (2) sedentary (i.e. <150min of moderate-intensity exercise per week (ACSM, 2006) for six months or more); (3) a score >14 on the stress component of the Depression, Anxiety and Stress Scale (DASS-21) (Lovibond & Lovibond, 1995) indicating mild stress; (4) no diagnosed chronic diseases; 5) no acute or chronic medical condition that would make Bikram yoga potentially hazardous (e.g. pregnancy) or outcomes difficult to assess; (6) able to attend three to five Bikram yoga classes per week for 16 weeks; (7) cognition and English language sufficient to understand research procedures and provide informed consent; (8) no participation in Bikram yoga in the past six months. Participants were recruited between August 2014 and September 2015 in the Australian Capital Territory (ACT). Data collection was completed by January 2016.

Intervention

Participants in the experimental group engaged in 16-weeks of Bikram yoga classes free of charge at either of two affiliated Bikram yoga studios in Canberra, ACT. Participants were instructed to attend three to five regularly scheduled classes per week. Certified Bikram yoga teachers instructed all classes using the standard instructional dialogue. Classes were 90 minutes in duration and held in a temperature-controlled room (40.6°C, 40% humidity). Details of the 90-minute Bikram yoga practice are described elsewhere (Choudhury, 2007; Hewett et al., 2015). Participants were treated as normal beginner students by the instructors.

Data collection

Adherence

Adherence was recorded as the total number of classes attended, and was recorded electronically upon arrival at each respective studio via an online booking system controlled by reception staff.

Predictors of adherence

All data, including demographics, behaviours and health status, were collected during the screening process and baseline data collection sessions (Hewett et al., 2017). Demographic variables included age and sex. Behavioural variables included smoking status, previous yoga experience and previous Bikram yoga experience. Participant choice of studio location was also determined. Depression, anxiety and stress levels were collected via the DASS-21 (Lovibond & Lovibond, 1995). Perceived stress was measured by the 10-item Perceived Stress Scale (PSS) (Cohen, 1988). The 10-item General Self-Efficacy (GSE) scale was used to assess general self-efficacy (Schwarzer et al., 1999) and a 5-item questionnaire was used to assess exercise self-efficacy (Schwarzer & Renner). HRQoL was assessed by the *RAND 36-Item Health Survey 1.0* (SF36) (Brazier et al., 1992). The SF-36 is comprised of eight separate HRQoL domains: physical functioning, social functioning, emotional well-being, energy/fatigue, pain, physical role limitations, emotional role limitations and general health. Heart rate variability (HRV) variables and augmentation index (AIx) were assessed via the SphygmoCor system and HRV software (SphygmoCor, AtCor Medical Pty, Sydney, Australia) using standard procedures (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). HRV variables included the absolute high frequency (HF) power component of HRV, absolute low frequency (LF) power component of HRV, LF/HF ratio, total power, percentage of absolute differences between successive normal r-wave to r-wave intervals that exceed 50ms (pNN50), standard deviation of the normal-normal interval (SDNN), root-mean-square of the successive normal sinus RR interval difference (RMSSD) and triangular index. Body composition (body fat percentage, lean body mass, fat mass, fat free mass) was assessed using a Lunar Prodigy Pro™ Dual-energy X-ray Absorptiometry (DXA) scan analysed with manufacturer software (enCORE™ v 14.1 software, GE Healthcare, Sydney, Australia) and anthropometric outcomes including body weight, body mass index (BMI) and waist circumference, were assessed using standardised procedures (ACSM, 2010). Resting heart rate and resting brachial systolic and diastolic blood pressures were assessed using an automatic monitor (M10-IT, Omron Inc., Japan) using standard procedures (ACSM, 2010). Haematological measures, assessed via standard blood collection procedures and assays (coefficients of variation: 2.0% – 4.2%), included total cholesterol, high density lipoprotein (HDL), total cholesterol to HDL ratio, low density lipoprotein (LDL), triglycerides, fasting blood glucose and c-reactive protein (CRP).

Barriers to adherence

Adverse events were documented throughout the trial via weekly status checks with participants. At the completion of all data collection, all participants were asked to complete an exit survey consisting of eight short-answer questions to gather participant feedback about the trial and the intervention (Table 7.1). The survey was delivered via email, and participants had the option of returning the survey via email or post. Exit survey responses were kept anonymous to the researcher during analysis.

Table 7.1 Exit Survey Questions

1. How did you find out about the trial? (e.g. Facebook post, flyer at local shops, friend)
2. Do you feel the written information and discussions with the principal researcher adequately explained what your involvement in the trial would be like?
3. What was the best part of your involvement in the trial? *This question is about the trial itself rather than the yoga classes, if you attended them.*
4. What was the most difficult part of your involvement in the trial? *This question is about the trial itself rather than the yoga classes, if you attended them.*
5. If you were assigned to the yoga group, could you please describe your overall experience of receiving the intervention?
6. What were the main benefits you got from your participation in the trial? *If there was nothing, please write that.*
7. Would you recommend this trial or a similar trial in the future to friends, family, colleagues etc.?
8. Do you have any additional comments you'd like to make that have not been addressed by the above questions?

Statistical analyses

The characteristics of the sample were summarised using counts and percentages for categorical variables, and means and standard deviations for numeric variables. Natural logarithm transformations were applied to continuous variables showing positive skew, and accepted where normality was improved. Prior to analysis of predictors, outlier attendance scores for participants who attended greater than 48 classes (n = 3) were reassigned a maximum score of 48 (minimum classes required) in a process akin to Winsorizing. These adjustments were made to decrease the effect of influential observations on the analyses. Linear regression models were applied to investigate continuous and categorical variables as predictors of class adherence. Variables were also checked for excessive correlation between predictors but none were found. A p-value < 0.05 was considered indicative of statistical significance with p-values < 0.10 providing weaker evidence of association. Variables were then selected for inclusion in a multiple regression analysis based on clinical plausibility and with consideration for not overfitting the model. Fitted regression models are presented using p-values, R-squared values and regression coefficients. All quantitative analyses were carried out using SPSS (IBM©, Version 23). Adverse events and exit surveys were analysed qualitatively. Responses were collated for each exit survey question and common responses were identified and illustrated with participant quotes. For example, responses stating that improvements to physical health were the best part of the trial were grouped together, as were responses stating that mental health benefits were the best part of the trial.

7.4 Results

Baseline characteristics for experimental group participants (n = 29) are presented in Table 7.2. The cohort was predominantly female (79%), aged 23 to 64 years, and primarily Bikram-yoga naïve (86%). More than a third of the group met the clinical criteria for obesity (BMI >30kg/m^2), while 45% were in the overweight category (i.e. BMI 25-29.9kg/m^2). The DASS-21 stress score indicated a moderate level of stress. Participants attended 27 ± 18 classes (range: 4 to 79) over the 16-week trial period. After adjusting for outliers, participants attended 54% (26 ± 15, range: 4 to 48) of the minimum 48 prescribed classes.

Table 7.2: Baseline characteristics

Characteristic	Yoga group n = 29
Age (years)	38.2 ± 10.1
Women (n; %)	23; 79%
Body weight (kg)	86.4 ± 21.2
Body mass index (BMI) (kg/m^2)	29.9 ± 6.2
Obese (BMI 30+) (n; %)	11; 38%
Waist circumference (cm)	93.9 ± 14.5
Depression score (DASS-21)	15.2 ± 10.7
Anxiety score (DASS-21)	9.2 ± 6.6
Stress score (DASS-21)	23.3 ± 6.0
Current smoker or quit in last 6 months (n; %)	1; 3%
<5 previous Bikram yoga classes	25; 86%

Continuous data presented as mean ± standard deviation
Abbreviations: DASS-21 = 21-item Depression-Anxiety-Stress-Scale
Depression categories: 0–9 = normal, 10–13 = mild, 14–20 = moderate, 21–27 = severe, 28+ = extremely severe
Anxiety categories: 0–7 = normal, 8–9 = mild, 10–14 = moderate, 15–19 = severe, 20+ = extremely severe
Stress categories: 15–18 = mild, 19–25 = moderate, 26–33 = severe, 34+ = extremely severe

Predictors of adherence

Baseline scores of seven variables were found have some evidence of association ($p < 0.10$) with adherence (Table 7.3). In summary, higher adherence to the Bikram yoga intervention was associated with older age, less pain, fewer physical limitations, poorer blood lipid profile (i.e. higher total cholesterol to HDL ratios, higher fasting blood glucose, lower HDL) and higher HRV (Ln total power).

HRQoL outcomes, including lower pain score ($p = 0.048$) and physical role limitations score ($p = 0.011$) were statistically significant predictors of adherence, and explained 21.6% and 13.7% of the variance in adherence, respectively. Haematological outcomes, including higher fasting blood glucose ($p = 0.011$), higher total cholesterol to HDL ratio ($p = 0.037$), and lower HDL ($p = 0.049$) explained 21.6%, 15.1%, and 13.6% of the variance in adherence, respectively. Variables which displayed only a weak evidence of association (p < 0.1), including age ($p = 0.094$) and HRV (total power; $p = 0.097$), explained 10.1% and 9.9% of the variance in adherence, respectively. As few participants were male, few were smokers and few had previous experience with Bikram yoga, we were unable to examine these variables' associations with adherence. Predictors ($p < 0.10$) were entered into a multi-variable regression analysis one by one. Three variables: age ($\beta = 0.492$, $p = 0.006$), HRV (total power) ($\beta = 0.413$, $p = 0.021$) and pain ($\beta = 0.329$, $p = 0.048$) remained significant predictors of adherence and collectively explained 41% of the variance in adherence in the model.

Table 3: Predictors of adherence (n = 29)

Variable	Significance (*p*-value)	*r*-value	Regression coefficient	95% Confidence interval
Categorical variables				
Male (compared to female)	0.682	-	+2.91	-11.51,17.34
Smoker (compared to non)	0.497	-	-10.70	-42.53,21.17
Previous yoga experience				
Bikram < 5 classes (compared to >5)	0.525	-	-5.29	-22.16,11.58
Non-Bikram < 5 classes (compared to >5)	0.308	-	-6.12	-18.21,5.97
South studio (compared to north)	0.143	-	+8.56	-3.08,20.21
Continuous variables				
Age	0.094*	0.317	+0.47	-0.09,1.03
Depression (DASS-21)	0.467	-0.141	-0.20	-0.75,0.35
Anxiety (DASS-21)	0.157	-0.270	-0.62	-1.49,0.25
Stress (DASS-21)	0.764	-0.058	-0.15	-1.14,0.85
Perceived stress scale	0.428	-0.153	-0.49	-1.74,0.76
General self-efficacy	0.154	0.272	+0.93	-0.37,2.24
Exercise self-efficacy	0.829	0.042	+0.16	-1.31,1.63
SF-36				
Physical functioning	0.491	0.133	+0.10	-0.20,0.41
Social functioning	0.179	0.257	+0.15	-0.07,0.37

Emotional well-being	0.540	0.119	+0.11	-0.26,0.49
Energy/fatigue	0.418	0.156	+0.15	-0.22,0.51
Pain	0.048*	0.371	+0.32	0.00,0.64
Role limiting – physical	0.011*	0.465	+0.23	0.06,0.41
Role limiting – emotional	0.198	0.246	+0.11	-0.06,0.28
General health	0.189	0.251	+0.20	-0.12,0.51
Heart Rate Variability				
Ln HF power (absolute)	0.548	0.116	+1.36	-3.21,5.92
Ln LF power (absolute)	0.197	0.247	+3.19	-1.18,8.14
LN LF/HF ratio	0.454	0.145	+2.31	-3.93,8.56
Ln total power	0.097*	0.314	+4.69	-0.90,10.28
pNN50	0.980	0.000	0.00	-0.28,0.28
Ln SDNN	0.221	0.234	+7.69	-4.90,20.27
Ln RMSSD	0.314	0.194	+4.53	-4.53,13.60
Ln triangular index	0.483	0.136	+4.53	-8.53,17.59
Body composition				
Body weight	0.631	-0.093	-0.07	-0.35,0.21
Body mass index	0.674	-0.082	-0.20	-1.16,0.76
Waist circumference	0.799	0.050	+0.05	-0.36,0.46
Body fat %	0.580	-0.109	-0.17	-0.81,0.46
Fat mass	0.662	-0.086	-0.09	-0.50,0.32
Lean mass	0.774	0.057	+0.08	-0.49,0.65
Fat-free mass	0.716	0.072	+0.10	-0.45,0.64
Haemodynamic measures				
Resting heart rate	0.292	-0.203	-0.38	-1.12,0.35

Systolic blood pressure	0.205	0.242	+0.33	-0.19,0.85
Diastolic blood pressure	0.237	0.227	+0.44	-0.30,1.17
Augmentation index	0.626	0.110	+0.18	-0.56,0.91
Haemotological measures				
Total cholesterol	0.662	0.085	+1.52	-5.53,8.58
LDL	0.334	0.190	+3.83	-4.17,11.82
HDL	0.049*	-0.368	-10.6	-21.17,-0.03
TC:HDL	0.037*	0.389	+4.75	0.31,9.18
Triglycerides	0.259	0.217	+3.50	-2.73,9.74
Fasting blood glucose	0.011*	0.465	+12.13	3.01,21.24
Ln hsCRP	0.179	-0.257	-2.87	-7.15,1.40

* = included in analysis. Abbreviations – DASS-21: 21-item Depression-Anxiety-Stress Scale; SF-36: RAND 36-Item Health Survey 1.0; HF: high frequency; LF: low frequency; pNN50: percentage of absolute differences between successive normal RR intervals that exceed 50ms; SDNN: standard deviation of the normal-normal interval; RMSSD: root-mean-square of the successive normal sinus RR interval difference; HDL: high-density lipoprotein; TC:HDL: ratio of total cholesterol to HDL; LDL: low-density lipoprotein; hsCRP: high sensitivity c-reactive protein.

Barriers to adherence

Exit surveys & adverse events

Twelve (41%) exit surveys were returned from the experimental group. When asked what the best part of the trial was, the responses from 50% of the experimental group participants were related to learning about and improving themselves. Three participants (25%) reported that the best part was assessing their health through the data collection testing sessions. When asked what the main benefits of participation in the trial were, five (42%) of the experimental group participants gave responses that described improvements in both physical and mental well-being. Two of the 12 participants (17%) who reported a lack of enjoyment of the intervention, also reported that the main benefit of participating in the trial was "Pride in this stint of self-care…motivation to keep engaging in self-care activities" and "it motivated me to seek out exercise options that were better suited to me".

When asked about the most difficult aspect of the trial, seven responses (58%) related to the obligations and commitment of being a participant. Explanations for commitment difficulties included arranging with partner to watch the children during class time, choosing between attending class and spending time with one's children, and juggling other commitments to prioritise class attendance. Anecdotally, one participant reflected that with her job demands and young family, prioritising the time required by the trial, regardless of intervention, would have been difficult. Overall experiences across the experimental group of the Bikram yoga itself were reported as positive by six (50%) participants. For example: "*I could manage stress more easily and noticed increased confidence*", "*a challenge but also an opportunity to experience my body doing postures I'd not thought I could do at this time in my life*", and "*amazing. So difficult! But an incredible achievement!*". Two responses (17%) were negative, for example: "*I didn't like going to classes at all. Bikram yoga is not right for me*" and "*I think that I entered the trial at the wrong point in my life….I also found* *that the time each class took out of my day was an added source of stress and I often felt guilty for being unable to attend the requested amount of classes*". Four participants (33%) had mixed feelings about the trial. For example, three participants (25%) stated that they enjoyed classes initially and could make time to attend but over the course of the trial this became more difficult or the enjoyment decreased. All participants in the experimental group except for one ("*too much of a commitment*") reported that they would recommend this trial or a similar trial to others in the future. One participant stated that the data collection location was inconvenient.

Six participants attributed exacerbation of a pre-existing condition to the intervention (i.e. back pain, foot pain, knee pain, calf pain, psychological discomfort). One additional participant experienced a non-intervention related event (sprained ankle). Before or during week eight, four of these seven participants discontinued the intervention completely (8 ± 4 classes attended). The other three continued (28 ± 11 classes attended). Adverse events that lead to discontinuation of the intervention reduced the average adherence from 60% to 54%.

7.5 Discussion

This study investigated predictors of and barriers to Bikram yoga participation in a cohort of stressed and sedentary adults. Higher adherence to the intervention was predicted independently by less pain, fewer physical limitations, poorer blood lipid profile (i.e. higher total cholesterol to HDL ratios, higher fasting blood glucose, lower HDL), older age, and higher HRV (Ln total power). In multi-variable analysis, age, HRV (total power) and pain remained significant predictors of adherence and collectively explained 41% of the variance in adherence.

Our cohort ranged in age from 23 to 64 years, and older age explained 10% of the variance in adherence ($p = 0.094$). Physical activity typically declines with age (Hallal et al., 2012). However, studies in metabolically diseased and overweight-obese populations have reported that age is positively associated with adherence to exercise and lifestyle intervention (Bautista-Castano et al., 2004; Kovač Blaž & Švab, 2015; Susin et al., 2016; Tobi et al., 2012). Similar findings exist in the yoga literature. For example, adults engaged in yoga, including those who participated in yoga to help with a primary medical complaint (Cramer et al., 2013) are more likely be middle-aged than younger (Park et al., 2015; Ross et al., 2012). By contrast, Baird et al. (2016) found no association between age and Bikram yoga attendance in an RCT of stressed females with disordered eating aged 25-45 years. Factors that may contribute to greater Bikram yoga uptake by our older participants may have included fewer work and family obligations, greater awareness of ageing and age-related susceptibility to morbidity, greater perceived health benefit of the practice, greater desire to participate in supervised exercise, and higher self-efficacy (Jerome & McAuley, 2012). Self-efficacy was found to be positively correlated with age in the present cohort (chapter six). Age-related increase in altruism, including respect for the research process, may have also influenced adherence. Further research is warranted to further explain age as a predictor of adherence to Bikram yoga, and to determine factors that may enhance adherence in younger adults who are stressed and sedentary.

Higher HRV (total power), a reflection of increased parasympathetic and reduced sympathetic activity (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996), explained 9.9% of variance in adherence (p = 0.097), suggesting that participants with lower physiological stress levels at baseline were more likely to adhere to the intervention. Higher HRV is associated with lower perceived (psychological) stress (Dishman et al., 2000), and perceived stress is a barrier to engagement in exercise (Sherwood & Jeffery, 2000; Stetson et al., 1997). Habitual exercisers report that during times of higher stress, enjoyment and satisfaction of exercise decreases ($p < 0.05$), and self-efficacy ($p < 0.01$) for meeting exercise goals decreases (Stetson et al., 1997). Further investigation is required to determine how physiological (i.e. lower HRV) and psychological stress interrelate and impact upon coping skills and adherence to Bikram yoga intervention.

Participants with less pain ($p = 0.048$) and fewer physical limitations ($p = 0.011$) at baseline may have been better able to cope with the demands of the Bikram yoga intervention. Similarly, Cadmus-Bertram et al (2014) reported that lower levels of pain predicted higher adherence to a 12-month exercise program in a cohort of sedentary, overweight (BMI 25-29.9kg/m^2) adults. Evidence suggests that *hatha* yoga can reduce pain compared to no-treatment (Posadzki et al., 2011). Bikram yoga has been shown to improve strength, flexibility and balance (Hewett et al., 2015), and these effects may possibly be associated with a reduction in physical limitations and pain. A recent review suggests that adherence to therapeutic exercise in populations with pain and physical limitations (i.e. osteoarthritis, low back pain) could be enhanced by a more graded approach to increasing exercise dosage (Nicolson et al., 2017). Perhaps a graded approach to Bikram yoga intervention in participants with pre-existing pain or physical limitations may improve adherence. Further research is warranted.

Higher total cholesterol to HDL ratio, higher fasting blood glucose, and lower HDL at baseline predicted adherence to the intervention. These results are congruent with our findings for age in that aging is associated with a progressive decline in metabolic health (Warburton et al., 2006). The same reasons for age-related adherence may indirectly explain these results. A previous study reported that a sub-group of participants with metabolic conditions (i.e. diabetes, hyperlipidaemia) were more likely to adhere to exercise compared to sub-groups of participants with cardiovascular or orthopaedic conditions (Tobi et al., 2012). It is important to note, however, that the cohort in the present study had metabolic disease risk factors only (i.e. sedentary, stressed), therefore comparisons with cohorts with confirmed metabolic disease must be made with caution.

Variables associated with enhanced adherence to non-Bikram yoga interventions, including higher self-efficacy, lower fatigue, reduced anxiety, lower waist circumference, and lower BMI (Cadmus-Bertram et al., 2013; Flegal et al., 2007; Speed-Andrews et al., 2012), did not predict adherence in the present study. A potential explanation for these incongruent findings requires further exploration using larger sample sizes than present (n = 29).

Our qualitative investigation suggests that the main barriers to adherence related to the required commitment to the trial and lack of enjoyment of the intervention. Similarly, previous Bikram yoga trials mentioned briefly that experimental group dropouts were attributed to either scheduling conflicts or lack of enjoyment of the intervention (Hewett et al., 2011; Hunter et al., 2017; Hunter et al., 2016; Tracy & Hart, 2013). Modern life, for example work and family commitments, has been identified as a major barrier ongoing yoga practice (Dayananda et al., 2014). As one participant reflected, commitment to any intervention for the time required by the current trial would have been difficult with her work and family commitments. The two participants who disliked Bikram yoga both reported that involvement in the trial motivated them to seek self-care activities that suited them better. Supporting this finding, previous studies suggests that *hatha* yoga intervention increases non-yoga physical activity in previously inactive adults (Bryan et al., 2012; Yang & James, 2016). Three participants reported that enjoyment waned over the course of the trial. A cross-sectional report has shown that yoga practice is often initiated for exercise and stress-relief; however, ‘spirituality’ was the top reason for ongoing participation (Park et al., 2016). Enhancing the understanding of how *hatha* yoga can fit into a healthy lifestyle may help to overcome perceived barriers to yoga adherence. Adverse events due to pre-existing conditions were also barriers to adherence in the current trial and contributed to complete discontinuation of the intervention in four participants. Additional research is required to determine what types of health issues may be exacerbated by participation in Bikram yoga, and how methodology might influence pre-existing conditions.

The major strength of this study is that it is the first examination of factors predicting and acting as perceived barriers to Bikram yoga. Secondly, the intervention took place in established Bikram yoga studios and participants attended classes with regular students of varying experience levels. Although this introduces more uncontrolled factors into the treatment experience it mimics the real-life experience of joining Bikram yoga as a beginner. Limitations of the trial include the modest sample size (n = 29) and low return rate of the exit surveys (12/29, 41%). Further, limited demographic data was collected, reducing the ability to explore a range of other possible predictors of adherence, including income, occupation, level of education, and geographic location (i.e. access to the studio). Future research should prioritise investigation into the minimum dose of Bikram yoga required for adaptation of various health outcomes, which may lead to improved adherence. Considering the low adherence to the intervention, future research should also consider that Bikram yoga may not be a suitable or enjoyable activity for some people. Following voluntary enrolment, future research should consider ways to effectively identify and reduce individual perceived barriers to Bikram yoga adherence, for example, through pre-intervention planning sessions. Lastly, yoga research is generally limited by the heterogeneity of both interventions themselves and reporting of data (Posadzki et al., 2014; Posadzki et al., 2015; Ward et al., 2014). Future research should consider common guidelines for conducting yoga trials (Sherman, 2012; Ward et al., 2014).

Conclusion

In summary, our findings show that higher adherence to a 16-week Bikram yoga intervention was independently predicted by older age, less pain, fewer physical limitations, poorer blood lipid profile (i.e. higher total cholesterol to HDL ratios, higher fasting blood glucose, lower HDL) and higher HRV (Ln total power). Barriers to the intervention included lack of enjoyment of the intervention, time commitment to participate in the trial, and adverse events. These findings should be considered in the development of future trials of Bikram yoga in similar cohorts, to facilitate higher levels of adherence, which may better inform community practice. Future trials should also continue to investigate and address additional barriers and facilitators of Bikram yoga practice.

Chapter 8

Summary & Conclusions

8.1 Overall summary

The overall objective of this doctoral research program was to build upon and strengthen the current quality of Bikram yoga research by reviewing the literature and implementing a randomised controlled trial (RCT) to evaluate the effect of Bikram yoga intervention on physiological and psychological health outcomes in sedentary and stressed adults. An additional aim was to investigate factors contributing to Bikram yoga adherence, to facilitate greater uptake in future RCTs. This thesis contributes to the current understanding of Bikram yoga intervention in several key areas.

Aim 1: ***To critically review and summarise the existing literature on Bikram yoga and provide recommendations for future trials***

In chapter three, a critical review of the existing literature on Bikram yoga has been presented to summarise the evidence base and provide recommendations for future trials (Hewett et al., 2015). Bikram yoga research published after the completion of this review has been included in the general literature review in chapter two. In summary, Bikram yoga RCTs published to date have reported favourable effects on strength, flexibility and balance, cortisol reactivity, distress tolerance and emotional eating. Further RCTs are required to support these preliminary findings. Non-RCTs report that Bikram yoga may improve glucose tolerance, blood lipid profile, arterial stiffness, bone mineral density, mindfulness, and perceived stress in some populations. Only a few studies have used an RCT design and intention-to-treat analysis, and predominantly healthy cohorts have been studied. Adherence data has been largely underreported and the dose-response effects of Bikram yoga remain unknown. The findings from the literature review led to the development of a RCT evaluating the effect of a 16-week Bikram yoga intervention on physiological and psychological outcomes in a cohort of stressed and sedentary adults. The general literature review and methodology for this study have been presented in chapters two and four, respectively.

Aim 2: ***To investigate the effect of a 16-week Bikram yoga intervention on the high-frequency power component of heart rate variability, secondary measures of heart rate variability, and associated cardiovascular disease risk factors (i.e. haemodynamic, anthropometric and haematological)***

Chapter five presented the physiological findings from the RCT. The 16-week Bikram yoga intervention (prescribed three to five classes per week) did not increase the high frequency (HF) power component of heart rate variability (HRV), secondary HRV variables, or any other cardiovascular disease (CVD) risk factors investigated in this cohort of stressed and sedentary adults. Low adherence (27 ± 18 classes attended) likely contributed to these findings. Regression analyses indicated a dose-response effect in that higher attendance was associated with significant reductions in diastolic blood pressure (p = 0.039), body fat (p = 0.001), fat mass (p = 0.003) and body mass index (p = 0.05), and weaker associations were noted between higher attendance and reduced systolic blood pressure (p = 0.072), body weight (p = 0.062), waist circumference (p = 0.072), and increased high-density lipoprotein (HDL) cholesterol (p = 0.052). No associations between adherence and any HRV variables, including the primary outcome, the high frequency component of HRV, were noted.

Aim 3: ***To investigate the effect of a 16-week Bikram yoga intervention on measures of psychological health status (i.e. psychological stress, self-efficacy, quality of life)***

Chapter six presented the psychological findings from the RCT. The 16-week Bikram yoga intervention (prescribed three to five sessions per week) reduced perceived stress ($p = 0.003$), increased general and exercise self-efficacy ($p = 0.034$; $p = 0.003$), and improved the general health ($p = 0.034$) and energy/fatigue ($p = 0.019$) domains of health-related quality of life (HRQoL). The intervention did not improve the physical functioning, social functioning, physical role limitations, emotional role limitations, pain and emotional well-being domains of HRQoL (all $p > 0.05$). Regression analyses indicated a dose-response effect in that higher attendance was associated with significant reductions in perceived stress ($p = 0.03$), significant increases in general self-efficacy ($p = 0.002$), and significant increases in general health ($p = 0.003$), energy/fatigue ($p = 0.022$) and emotional well-being ($p = 0.022$).

Aim 4*: To investigate predictors of and barriers to adherence to the 16-week Bikram yoga.*

Chapter seven investigated predictors of and barriers to adherence to the Bikram yoga intervention applied in the RCT. As mentioned, intention-to-treat analysis revealed poor adherence to the intervention (27 ± 18 classes attended). Adherence to the minimum prescribed classes over the course of the 16-week intervention (i.e. 48 classes) was independently predicted by reduced pain, fewer physical role limitations, poorer metabolic profile (i.e. higher total to HDL cholesterol ratio, higher fasting blood sugar, lower HDL cholesterol), older age and higher HRV (Ln total power). Main barriers to the intervention included time commitment of the trial, lack of enjoyment of the intervention, and adverse events.

8.2 Conclusion and future research directions

In conclusion, this research has made a significant contribution to furthering the current understanding of Bikram yoga intervention in sedentary and stressed adults through a narrative review of existing research, and by conducting a rigorous, intention-to-treat RCT. Review of the current literature reveals that Bikram yoga may positively affect fitness outcomes, psychological outcomes, and some physiological outcomes in certain populations. Current research is lacking in quality and depth. Evidence from the 16-week RCT reported positive adaptation of perceived stress, general and exercise self-efficacy and HRQoL, and little to no effect on HRV and CVD risk factors in sedentary and stressed adults. However, a dose-response effect appears to exist. Adherence was influenced by several baseline characteristics, and inhibited by time constraints, enjoyment of Bikram yoga, and adverse events.

Importantly, this work highlights critical areas of development for future, rigorous investigations into the effects of Bikram yoga on health in sedentary populations at-risk for CVD. Considering the associations of adherence with adaptation of certain physiological outcomes, future research could, under appropriate medical clearance and supervision, explore the effects of Bikram yoga on CVD outcome measures in larger samples of unhealthy, higher-risk populations to better examine the effects of this form of heated *hatha* yoga on CVD risk factors. Such populations may include those with impaired glucose management or hypertension. Populations at higher-risk for psychological illness, including those with posttraumatic stress disorder and anxiety disorders, should also be included in future research studies given the positive effect of Bikram yoga on psychological health outcomes in the present study. A priority for future research is the investigation into the minimum dose of Bikram yoga required for adaptation of various health outcomes in varying populations, and investigations should consider ways to effectively identify and reduce individual perceived barriers to Bikram yoga adherence. Adherence may be improved by conducting all classes with one instructor, and by more specific pre-intervention engagement with participants to discuss and prepare for barriers to adherence and to discuss how regular *hatha* yoga practice can contribute to a healthy lifestyle. Finally, regardless of topic investigated, future trials should adhere to CONSORT guidelines for study design and reporting. A collaborative effect is required to advance the growing understanding of Bikram yoga via high-quality, rigorous investigations.

In summary, the current body of literature, including this thesis, suggests that Bikram yoga may have some effect on health outcomes, however, it is too early to state that that Bikram yoga can be used as an effective alternative or complement to traditional exercise training that improves physiological and psychological health in various populations. It is also currently unclear how or if the heated environment contributes to potential changes to health. The focus for future studies should be to further our understanding of Bikram yoga through robust intention-to-treat RCT design in larger samples of higher risk populations, with consideration of potential barriers to adherence.

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Appendix

Appendix 1. Intervention protocol

Participants were prescribed three to five Bikram yoga classes per week for 16 weeks. Each class was led by certified Bikram yoga instructors, was 90-minutes in duration and involved the performance of the following sequence of breathing exercises and *asanas*:

Key:

a. *Pranayama* (standing deep breathing)
b. *Ardha-chandrasana* with *pada-hasthasana* (half-moon pose with hands to feet pose)
c. *Utkatasana* (awkward pose)
d. *Garurasana* (eagle pose)
e. *Dandayamana-janushirasana* (standing head to knee pose)
f. *Dandayamana-dhanurasana* (standing bow pulling pose)
g. *Tuladandasana* (balancing stick pose)
h. *Dandayamana-bibhaktapada-paschimotthanasana* (standing separate leg stretching pose)
i. *Trikanasana* (triangle pose)
j. *Dandayamana-bibhaktapada-janushirasana* (standing separate leg head to knee pose)
k. *Tadasana* (tree pose)
l. *Padangustasana* (toe stand pose)
m. *Savasana* (dead body pose)
n. *Pavanamuktasana* (wind removing pose)
o. Sit-up
p. *Bhujangasana* (cobra pose)
q. *Salabhasana* (locust pose)
r. *Poorna-salabhasana* (full locust pose)
s. *Dhanurasana* (bow pose)
t. *Supta-vajrasana* (fixed firm pose)
u. *Ardha-kurmasana* (half tortoise pose)
v. *Ustrasana* (camel pose)
w. *Sasangasana* (rabbit pose)
x. *Janushirasana* (head to knee with stretching pose)
y. *Paschimotthanasana* (stretching pose)
z. *Ardha-matsyendrasana* (spine twisting pose)
aa. *Kapalbhati in vajrasana* (blowing in firm pose)

Each posture was performed twice (consecutively) except for *ardha-matsyendrasana* which was performed once only. *Savasana* was performed first for two minutes, and subsequently between each of the floor-based postures for 20 seconds. A final *savasana* was used to conclude the class after *kapalbhati* in *vajrasana*.

Appendix 2. Participant consent form

Human Research Ethics Committee
Office of Research Services

University of Western Sydney

Participant Consent Form

Project Title: A randomised controlled trial of a 16-week Bikram yoga program on heart rate variability and cardiovascular risk factors in sedentary adults.

I,.., consent to participate in the research project titled A randomised controlled trial of a 16-week Bikram yoga program on heart rate variability and cardiovascular risk factors in sedentary adults.

I acknowledge that:

I have read the participant information sheet and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s.

The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

I consent to keeping a record of my activity and diet, and at baseline and follow-up undertaking fasting blood tests at Capital Pathology, as well as several tests and questionnaires at the University of Canberra (dual-energy x-ray absorptiometry scans, treadmill test, heart rate variability measurement). I also consent to complete 3-5 Bikram yoga classes per week if I am randomised to the experimental group, or continue with my normal activity level if I am randomised to the control group.

I understand that my involvement is confidential and that the information gained during the study may be published but no information about me will be used in any way that reveals my identity.

I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher/s now or in the future.

Signed: ________________________________

Name: ________________________________

Date: ________________________________

Return Address:

This study has been approved by the University of Western Sydney Human Research Ethics Committee.

The Approval number is: H10549

If you have any complaints or reservations about the ethical conduct of this research, you may contact the Ethics Committee through the Office of Research Services on Tel +61 2 4736 0229 Fax +61 2 4736 0013 or email humanethics@uws.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix 3. Participant information sheet

School of Science and Health
University of Western Sydney
Locked Bag 1797
Penrith NSW 2751
Australia
Telephone : 0421786333
e-mail :13521266@student.uws.edu.au

University of Western Sydney
Bringing knowledge to life

Participant Information Sheet (General)

Project Title: A randomised controlled trial of a 16-week Bikram yoga program on heart rate variability and cardiovascular disease risk factors in sedentary adults.

Project Summary: Cardiovascular disease (CVD) is the leading cause of death worldwide. Heart rate variability (HRV), along with traditional measures, is being used increasingly to assess CVD risk. Low HRV, which is also a risk factor for disease and mortality, has been linked to several CVD risk factors including reduced cardiorespiratory fitness, systemic inflammation, metabolic syndrome markers, and increased stress.

Research suggests that chronic stress plays a significant role in the development of chronic diseases, including obesity and CVD. Aerobic exercise is often used to prevent and teat chronic diseases such as obesity and CVD, and meditation has been shown to effectively reduce stress. Bikram yoga is a form of hatha yoga, which incorporates physical activity and relaxation into the same activity. Bikram yoga may be an effective intervention for the treatment and prevention of stress- and physical inactivity-related chronic disease, however no study to date has investigated the effects of Bikram yoga on HRV in relation to CVD risk factors. Therefore, the purpose of this study is to investigate the effects of a 16-week Bikram yoga program on adults with CVD risk factors.

You are invited to participate in a study conducted by Zoe Hewett, PhD research student candidate at the University of Western Sydney Campbelltown.

Zoe Hewett is also part owner of one of the two yoga studios to be used in the intervention delivery. Your decision to participate or not will not affect your treatment during the study nor your involvement at the studio at other times.

How is this study being paid for?

The study is being sponsored by funds for Zoe Hewett to complete her PhD studies.

What will I be asked to do?

You will be randomly assigned (like the toss of a coin) to either a yoga group or a non-treatment control group. You will be required to attend two face-to-face testing sessions, one at the University of Canberra (UC) and one at Capital Pathology, for baseline and follow-up testing (i.e. before and after the 16-week intervention). The testing sessions will involve body composition assessment (DEXA technique involves a very low dose of radiation, less than a typical x-ray and less than the radiation exposure of an 8 hour plane flight), HRV assessment, cardiorespiratory fitness assessment, psychological questionnaires and blood tests. The blood tests will be carried out following an overnight fast. At the mid-point of the study some questionnaires will be repeated and participants in both groups will be offered the opportunity to meet with Zoe Hewett to discuss the program so far (via email, face-to-face, phone call depending on participants preference). For the duration of the study you will also be required to maintain an initial 7-day and subsequent weekly physical activity and diet log. Instructions on completing this diary will be provided at the beginning of the study. If you are allocated to the yoga group you will be required to complete 3-5 Bikram yoga classes per week. If you are allocated to the non-treatment control group, you will be required to continue with your usual lifestyle for the duration of the trial. Weekly communication between Zoe Hewett and participants will be used to document any adverse events or reactions.

How much of my time will I need to give?

Baseline and follow-up testing sessions will be 1-2 hours each. Each Bikram yoga class is 1.5 hours, not including travel time. The study extends for 18 weeks (i.e. testing weeks before and after a 16-week intervention period).

What specific benefits will I receive for participating?

If you are randomly assigned to the yoga training group, you will receive 4 months of unlimited yoga classes at the Canberra-based studios. Additionally, it is expected that your health status will improve. For example physical fitness, body composition, quality of life, and stress will potentially improve. If you are randomised into the non-treatment control group you will receive a complimentary 10-class pass to the certified Canberra studio of your choice (Mitchell or Kingston) valued at $180.

Will the study involve any discomfort for me? If so, what will you do to rectify it.

Bikram yoga sessions are conducted in a heated room (40 degrees celsius, 38% humidity) and are taught by certified Bikram yoga teachers. Some may find the heated environment initially uncomfortable, and at the least most find it unusual to start with. Each individual takes a certain amount of time to acclimatise to the environment. As a beginner you will be encouraged to pace yourself and take breaks if needed as you get use to the postures and the environment. You will be supported and monitored throughout the 16 weeks by the teachers and by the researcher, Zoe Hewett (also a certified Bikram yoga teacher). Initiating any exercise program that requires more involvement than current activity levels can lead to muscle soreness and mental challenges during and/or following exercise. Some participants may feel distressed when completing the questionnaires evaluating stress and quality of life, and even during the yoga classes. In the event that you are feeling upset or distressed because of, or during the trial, please contact the researcher Zoe Hewett on 0421786333 or 13521266@student.uws.edu.au. Alternatively, if you feel more comfortable, please use a free telephone service counselling service lifeline on 13 11 14, or contact your GP.

How do you intend on publishing the results.

All aspects of the study, including results, will be confidential and only the researchers will have access to information on participants. Your identity will not be made public. It is expected that the findings of the research will be published in a peer reviewed journal and presented at national and international congresses. All data will be kept for a minimum of five years.

There are a number of government initiatives in place to centrally store research data and to make it available for further research. For more information, see http://www.ands.org.au/ and http://www.rdsi.uq.edu.au/about. Regardless of whether the information you supply or about you is stored centrally or not, it will be stored securely and it will be de-identified before it is made to available to any other researcher.

Can I withdraw from the study?

Participation is entirely voluntary: and you are not obliged to be involved. If you do participate, you can withdraw at any time without giving any reason.

If you do choose to withdraw, any information that you have supplied may be used for the journal publication although your identify will not be revealed at any point

Can I tell other people about the study?

Yes, you can tell other people about the study by providing them with the chief investigator's contact details. They can contact the chief investigator to discuss their participation in the research project and obtain an information sheet.

What if I require further information?

Please contact Zoe Hewett should you wish to discuss the research further before deciding whether or not to participate.

Zoe Hewett, PhD Research Student 0421 786 333
Dr. Bobby Cheema, Senior Lecturer 0416 956 805

What if I have a complaint?

This study has been approved by the University of Western Sydney Human Research Ethics Committee. The Approval number is _____.

If you have any complaints or reservations about the ethical conduct of this research, you may contact the Ethics Committee through the Office of Research Services on Tel +61 2 4736 0229 Fax +61 2 4736 0013 or email humanethics@uws.edu.au.

Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

If you agree to participate in this study, you may be asked to sign the Participant Consent Form.

Appendix 4. Medical Screening and Eligibility

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Bringing knowledge to life

Participant_____________________________
Date _________________

Contact Information and Study Eligibility

Mobile Phone: ________________   Office phone: __________________

Home Phone: _________________   Email: ______________________
Preferred Method of Contact: Email / Mobile / Office Phone / Home Phone

Date of birth (dd/mm/yyyy): ________________

Gender: ____

Have you participated in Bikram yoga previously?   Yes / No
If yes, how long have you been practicing? _________________________

Are you currently practicing Bikram yoga? Yes / No

Have you practiced other forms of yoga? Yes/No
If yes, what forms and for how long?
____
____

If randomised into the control group, would you able to attend 3-5 90-minute Bikram yoga sessions a week (see www.bikramcanberra.com.au and www.bikramyogakingston.com.au for up-to-date schedules) for 16-weeks sometime between late now and Dec 2015?
Yes / No

If randomised into the control group, would you be willing to continue with your current level of activity/diet (essentially, make no changes) for the duration of the 16-week trial?
Yes / No

Physical Activity Readiness Questionnaire (PAR-Q)

The following questions are required for screening individuals prior to commencement of a new exercise program. Answers to the following questions are required to ensure your health and safety. PLEASE ANSWER ALL QUESTIONS HONESTLY. If you have any concerns about answering any question please see the research staff in private.

Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
Yes / No

Do you feel pain in your chest when you do physical activity?
Yes / No

In the past month, have you had chest pain when you were not doing physical activity?
Yes / No

Do you lose your balance because of dizziness or do you ever lose consciousness?
Yes / No

Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
Yes / No

Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
Yes / No

Do you know of any other reason why you should not do physical activity?
Yes / No

Medical History

1. List all medications you are taking along with condition for which they are taken:

2. Do you have diabetes? No / Yes (If Yes, circle type: Type 1 / Type 2)
   If Type 2, for how many years? _____ yrs

3. Have you had a stroke? Yes / No

4. Do you have difficulties breathing? Yes / No

5. Do you have liver or kidney disease? Yes / No

6. Are you, or do you have reason to believe, that you are pregnant? Yes / No

7. Have you, at any time in the last 12 months, had an attack of shortness of breath that came on during the day when you were not doing anything strenuous? Yes / No

8. Have you had an attack of shortness of breath that came on after you stopped exercising, at any time in the last 12 months? Yes / No

9. Do you often feel faint or have spells of severe dizziness, particularly with exercise? Yes / No

10. Have you at any time in the last 12 months been woken at night by shortness of breath? Yes / No

11. Do you experience swelling or accumulation of fluid about the ankles? Yes / No

12. Do you often get the feeling that your heart is beating faster, racing or skipping beats, either at rest or during exercise? Yes / No

13. Do you regularly get pains in your calves and lower legs during exercise, which are not due to soreness or stiffness? Yes / No

14. Has your doctor ever told you that you have a heart murmur? Yes / No

15. Do you often experience fatigue when you are not doing anything strenuous, or when you are not doing anything at all? Yes / No

16. Do you smoke cigarettes daily? Yes / No
If yes, how many cigarettes do you smoke each day on average?_________
If no, have you quit smoking within the last two years? Yes / No

17. Do you have a close relative (ie father, mother, brother or sister) who has had a stroke, heart attack or other cardiovascular disease? Yes / No

If yes, what relation was this person (eg father, sister):

____

At what age did he or she suffer a stroke/heart attack?:

____

Did your relative die suddenly as a result of a stroke or heart attack? Yes / No

18. Has your doctor ever told you that you have high blood pressure? Yes / No

19. Do you know your systolic blood pressure? Yes / No
If yes, what is it? ____________ mmHg

20. Do you know your diastolic blood pressure? Yes / No
If yes, what is it? ____________ mmHg

21. Do you know your serum cholesterol level? Yes / No
If yes, what is it? ____________ mmol.L^{-1}

22. Do you know your serum HDL level? Yes / No
If yes, what is it? ____________ mmol.L^{-1}

23. Do you have a pacemaker? Yes/No

24. Does your occupation involve sitting for a large part of the day? Yes / No

25. Have you experienced menopause before the age of 45? Yes / No

26. What is your waist circumference (cm)? *Stand with feet together, tape measure around waist between front hip bone and bottom rib* ______________

27. Are you currently involved in a regular exercise program? Yes / No

If yes, please describe (e.g., brisk walking for 30 minutes, 5 times a week:
____
____
____
____

27. Are you currently following any specific diet? Yes/No

If yes, please describe:
____
____
____

Office Use Only:

DASS________________

WC ________________

Activity ________________

Appendix 5. DASS-21

DASS21

Name: *Date:*

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

1	I found it hard to wind down	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I found it difficult to work up the initiative to do things	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I experienced trembling (eg, in the hands)	0	1	2	3
8	I felt that I was using a lot of nervous energy	0	1	2	3
9	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting agitated	0	1	2	3
12	I found it difficult to relax	0	1	2	3
13	I felt down-hearted and blue	0	1	2	3
14	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
15	I felt I was close to panic	0	1	2	3
16	I was unable to become enthusiastic about anything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I was aware of the action of my heart in the absence of physical exertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life was meaningless	0	1	2	3

Appendix 6. Perceived stress scale

Perceived Stress Scale

The questions in this scale ask you about your feelings and thoughts during the last month. In each case, you will be asked to indicate by circling how often you felt or thought a certain way.

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

1. In the last month, how often have you been upset because of something that happened unexpectedly? ………................................. 0 1 2 3 4

2. In the last month, how often have you felt that you were unable to control the important things in your life? 0 1 2 3 4

3. In the last month, how often have you felt nervous and “stressed”? 0 1 2 3 4

4. In the last month, how often have you felt confident about your ability to handle your personal problems? 0 1 2 3 4

5. In the last month, how often have you felt that things were going your way?…..0 1 2 3 4

6. In the last month, how often have you found that you could not cope with all the things that you had to do? …..0 1 2 3 4

7. In the last month, how often have you been able to control irritations in your life?...0 1 2 3 4

8. In the last month, how often have you felt that you were on top of things? …………….0 1 2 3 4

9. In the last month, how often have you been angered because of things that were outside of your control?..................................0 1 2 3 4

10. In the last month, how often have you felt difficulties were piling up so high that you could not overcome them? 0 1 2 3 4

Appendix 7. General self-efficacy

General Self-Efficacy Scale

Below are ten statements about yourself which may or may not be true. Using the 1-4 scale below, please indicate your agreement with each item by placing the appropriate number on the line following that item.

Please be open and honest in your responding.

The 4-point scale:

1	2	3	4
Not at all true	Hardly true	Moderately true	Exactly true

1. I can always manage to solve difficult problems if I try hard enough. ___

2. If someone opposes me, I can find the means and ways to get what I want. ___

3. It is easy for me to stick to my aims and accomplish my goals. ___

4. I am confident that I could deal efficiently with unexpected events. ___

5. Thanks to my resourcefulness, I know how to handle unforeseen situations. ___

6. I can solve most problems if I invest the necessary effort. ___

7. I can remain calm when facing difficulties because I can rely on my coping abilities. ___

8. When I am confronted with a problem, I can usually find several solutions. ___

9. If I am in trouble, I can usually think of a solution. ___

10. I can usually handle whatever comes my way. ___

Appendix 8. Exercise self-efficacy

Exercise Self-Efficacy Scale

"How certain are you that you could overcome the following barriers?"

(1) very uncertain, (2) rather uncertain, (3) rather certain, and (4) very certain.

I can manage to carry out my exercise intentions...

1. ...even when I have worries and problems. ___
2. ...even if I feel depressed. ___
3. ...even when I feel tense. ___
4. ...even when I am tired. ___
5. ...even when I am busy. ___

Appendix 9. Quality of life - RAND 36-Item Health Survey 1.0 (SF36)

SF-36 Health Status Survey

This survey asks you your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities.

1. In general, would you say your health is:

Excellent	Very Good	Good	Fair	Poor
○	○	○	○	○

2. Compared to one year ago, how would you rate your health in general now?

- ○ Much better now than 1 year ago
- ○ Somewhat better now than 1 year ago
- ○ About the same as 1 year ago
- ○ Somewhat worse now than 1 year ago
- ○ Much worse now than 1 year ago

3. The following items are about activities you might do during a typical day. Does **your health now limit you** in these activities? If so, how much?

Activities	**Yes, Limited A Lot**	**Yes, Limited A Little**	**No, Not Limited At All**
Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports	○	○	○
Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	○	○	○
Lifting or carrying groceries	○	○	○
Climbing **several** flights of stairs	○	○	○
Climbing **one** flight of stairs	○	○	○
Bending, kneeling or stooping	○	○	○
Walking **more than a mile**	○	○	○
Walking **several blocks**	○	○	○
Walking **one block**	○	○	○
Bathing or dressing yourself	○	○	○

4. During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of your physical health**?

	Yes	**No**
Cut down on the **amount of time** you spent on work or other activities	O	O
Accomplished less than you would like	O	O
Were limited in the **kind** of work or other activities	O	O
Had **difficulty** performing the work or other activities (for example, it took extra effort)	O	O

5. During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of any emotional problems** (such as feeling depressed or anxious)?

	Yes	**No**
Cut down on the **amount of time** you spent on work or other activities	O	O
Accomplished less than you would like	O	O
Didn't do work or other activities as **carefully** as usual	O	O

6. During the **past 4 weeks**, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbours, or groups?

- O Not at all
- O Slightly
- O Moderately
- O Quite a bit
- O Extremely

7. How much **bodily** pain have you had during the **past 4 weeks**?

- O None
- O Very mild
- O Mild
- O Moderate
- O Severe
- O Very severe

8. During the **past 4 weeks**, how much did **pain** interfere with your normal work (including both work outside the home and housework)?

- O Not at all
- O A little bit
- O Moderately
- O Quite a bit
- O Extremely

9. These questions are about how you feel and how things have been with you **during the past 4 weeks**. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time **during the past 4 weeks**….

	All of the Time	**Most of the Time**	**A Good Bit of the Time**	**Some of the Time**	**A Little Bit of the Time**	**None of the Time**
Did you feel full of pep?	○	○	○	○	○	○
Have you been a very nervous person?	○	○	○	○	○	○
Have you felt so down in the dumps that nothing could cheer you up?	○	○	○	○	○	○
Have you felt calm and peaceful?	○	○	○	○	○	○
Did you have a lot of energy?	○	○	○	○	○	○
Have you felt downhearted and blue?	○	○	○	○	○	○
Did you feel worn out?	○	○	○	○	○	○
Have you been a happy person?	○	○	○	○	○	○
Did you feel tired?	○	○	○	○	○	○

10. During the **past 4 weeks**, how much of the time has your **physical health or emotional problems** interfered with your social activities (like visiting with friends, relatives etc.)?

- All of the time
- Most of the time
- Some of the time
- A little of the time
- None of the time

11. How TRUE or FALSE is **each** of the following statements for you?

	Definitely True	**Mostly True**	**Don't Know**	**Mostly False**	**Definitely False**
I seem to get sick a little easier than other people	○	○	○	○	○
I am as healthy as anybody I know	○	○	○	○	○
I expect my health to get worse	○	○	○	○	○
My health is excellent	○	○	○	○	○

Appendix 10. International Physical Activity Questionnaire (IPAQ)

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. This is part of a large study being conducted in many countries around the world. Your answers will help us to understand how active we are compared with people in other countries.

The questions are about the time you spent being physically active in the last 7 days. They include questions about activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Your answers are important.

Please answer each question even if you do not consider yourself to be an active person.

THANK YOU FOR PARTICIPATING.

In answering the following questions,

- **vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder that normal.

- **moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder that normal.

This is the final SHORT LAST 7 DAYS SELF-ADMINISTERED version of IPAQ from the 2000/01 Reliability and Validity Study. Completed May 2001.

1a. During the last 7 days, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling,?

Think about *only* those physical activities that you did for at least 10 minutes at a time.

_______ **days per week** ⇨

or

☐ **none**

1b. How much time in total did you usually spend on one of those days doing vigorous physical activities?

_____ **hours** ______ **minutes**

2a. Again, think *only* about those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_______ **days per week** ⇨

or

☐ **none**

2b. How much time in total did you usually spend on one of those days doing moderate physical activities?

_____ **hours** ______ **minutes**

3a. During the last 7 days, on how many days did you **walk** for at least 10 minutes at a time? This includes walking at work and at home, walking to travel from place to place, and any other walking that you did solely for recreation, sport, exercise or leisure.

_______ **days per week** ⇨

or

☐ **none**

3b. How much time in total did you usually spend walking on one of those days?

_____ **hours** ______ **minutes**

The last question is about the time you spent sitting on weekdays while at work, at home, while doing course work and during leisure time. This includes time spent sitting at a desk, visiting friends, reading traveling on a bus or sitting or lying down to watch television.

4. During the last 7 days, how much time in total did you usually spend *sitting* on a **week day?**

____ **hours** ______ **minutes**

This is the end of questionnaire, thank you for participating.

This is the final SHORT LAST 7 DAYS SELF-ADMINISTERED version of IPAQ from the 2000/01 Reliability and Validity Study. Completed May 2001.

Appendix 11. 7-day Food Diary

INSTRUCTIONS FOR KEEPING A FOOD DIARY

A Food Diary can be a useful tool if used correctly because it gives you a chance to look at what you **REALLY** eat, rather than what you **THINK** you eat. The Food Diary can only be useful if it is a true indication of your typical eating habits.

Be honest and follow the following guidelines:

- ✓ Fill out the diary for 7 consecutive days
- ✓ Stick to your usual eating habits when you are recording. Don't eat better than usual to impress us. Don't only eat foods that are easy to record.
- ✓ Remember to include all the things that you add to food when eating or cooking (eg. margarine, oil, sugar, dressings).
- ✓ Please remember to describe foods in as much detail as possible (eg. white/wholemeal bread, fat left on/trimmed off, sweetened/unsweetened, full cream/reduced fat).
- ✓ List the ingredients and special features of mixed dishes such as pizza, pasta sauce, stir fries, casseroles.
- ✓ Only record food that is actually eaten. Don't record everything you put on your plate if you leave some behind.
- ✓ Record the quantity of foods and fluids as accurately as possible. E.g. don't just write "cereal + milk + fruit" write "6 weetbix + 1 Cup skim milk + 1 large banana.

You can use any of the following methods:

Weight **(often written on food packaging)**

ml **(know the volume of your drink bottle)**

Teaspoons **(heaped or level?)**

Cups **(but not bowls or plates they vary too much in size)**

Quantity **2 slices bread, 6 weetbix etc**

SAMPLE FOOD DIARY - DAY 1

MEAL TIME	**MEAL TYPE**	**Hunger Rating (*)1-10**
BREAKFAST *Time: 6am* *Location: Home*	2 Weetbix + 0.5 cup skim milk + 1 large banana + 2 teaspoons sugar. 1 slices multigrain toast + margarine (thick) + vegemite 300mL glass orange juice + 1 mug milo	6
MORNING TEA *Time: 10.30am* *Location: work*	50g packet chips + 200g tub low fat yoghurt + 2 apples 1 x cappuccino, skim milk and 1 sugar (regular size)	9
LUNCH *Time:12.30pm* *Location: work*	2 x sandwiches – 4 slices wholemeal bread, no spread + 150g chicken breast + 4 slices tomato + lettuce + salt. 2 x yoghurt covered muesli bars + 1 medium orange 600mL water	7
AFTERNOON TEA *Time: 5pm* *Location: car on way home*	1 x apple and 10 rice crackers	6
DINNER *Time: 7.15pm* *Location: Home*	200g lean beef mince + 3 Cups pasta (white, cooked) + Paul Newman sauce (tomato, basil) + 1 cup broccoli + carrots 0.5 bottle of red wine 2 large scoops ice cream (full fat) + 200g tinned fruit in natural juice	8
DESSERT/SUPPER Time: 9pm Location: Home	300mL low fat milk + 4 teaspoons milo	5

(*)HUNGER RATING: (1 = No Appetite, 10 = Extremely Hungry)

FOOD DIARY - DAY 1

MEAL TIME	**MEAL TYPE**	**Hunger Rating (*)1-10**
BREAKFAST *Time:* *Location:*		
MORNING TEA *Time:* *Location:*		
LUNCH *Time:* *Location:*		
AFTERNOON TEA *Time:* *Location:*		
DINNER Time: Location:		
DESSERT/SUPPER Time: Location:		

(*)HUNGER RATING: (1 = No Appetite – 10 = Extremely Hungry

FOOD DIARY - DAY 2

MEAL TIME	**MEAL TYPE**	**Hunger Rating (*)1-10**
BREAKFAST *Time:* *Location:*		
MORNING TEA *Time:* *Location:*		
LUNCH *Time:* *Location:*		
AFTERNOON TEA *Time:* *Location:*		
DINNER Time: Location:		
DESSERT/SUPPER Time: Location:		

(*)HUNGER RATING: (1 = No Appetite – 10 = Extremely Hungry

FOOD DIARY - DAY 3

MEAL TIME	**MEAL TYPE**	**Hunger Rating (*)1-10**
BREAKFAST *Time:* *Location:*		
MORNING TEA *Time:* *Location:*		
LUNCH *Time:* *Location:*		
AFTERNOON TEA *Time:* *Location:*		
DINNER Time: Location:		
DESSERT/SUPPER Time: Location:		

(*)HUNGER RATING: (1 = No Appetite – 10 = Extremely Hungry

FOOD DIARY - DAY 4

MEAL TIME	**MEAL TYPE**	**Hunger Rating (*)1-10**
BREAKFAST *Time:* *Location:*		
MORNING TEA *Time:* *Location:*		
LUNCH *Time:* *Location:*		
AFTERNOON TEA *Time:* *Location:*		
DINNER Time: Location:		
DESSERT/SUPPER Time: Location:		

(*)HUNGER RATING: (1 = No Appetite – 10 = Extremely Hungry

FOOD DIARY - DAY 5

MEAL TIME	**MEAL TYPE**	**Hunger Rating (*)1-10**
BREAKFAST *Time:* *Location:*		
MORNING TEA *Time:* *Location:*		
LUNCH *Time:* *Location:*		
AFTERNOON TEA *Time:* *Location:*		
DINNER Time: Location:		
DESSERT/SUPPER Time: Location:		

(*)HUNGER RATING: (1 = No Appetite – 10 = Extremely Hungry

FOOD DIARY - DAY 6

MEAL TIME	MEAL TYPE	Hunger Rating (*)1-10
BREAKFAST *Time:* *Location:*		
MORNING TEA *Time:* *Location:*		
LUNCH *Time:* *Location:*		
AFTERNOON TEA *Time:* *Location:*		
DINNER Time: Location:		
DESSERT/SUPPER Time: Location:		

(*)HUNGER RATING: (1 = No Appetite – 10 = Extremely Hungry

FOOD DIARY - DAY 7

MEAL TIME	MEAL TYPE	Hunger Rating (*)1-10
BREAKFAST *Time:* *Location:*		
MORNING TEA *Time:* *Location:*		
LUNCH *Time:* *Location:*		
AFTERNOON TEA *Time:* *Location:*		
DINNER Time: Location:		
DESSERT/SUPPER Time: Location:		

(*)HUNGER RATING: (1 = No Appetite – 10 = Extremely Hungry

FOOD DIARY CHECKLIST

1. Who do you live with

   ☐ Family
   ☐ Alone
   ☐ Other. Please describe...

2. Who does the cooking? …………………………………………………..

   a. How would you describe their cooking skills

      ☐ Poor
      ☐ Average
      ☐ Great

3. Who does the shopping? …………………………………………………..

   a. How often? …………………………………………………..

4. Do you ever skip any meals? YES/ NO
5.
   a. If so which ones, and why? Reason

      ☐ Breakfast …………………………………..
      ☐ Morning tea …………………………………..
      ☐ Lunch …………………………………..
      ☐ Afternoon tea …………………………………..
      ☐ Dinner …………………………………..
      ☐ Supper …………………………………..

6. Over the 7 days of the week, how often do you eat out? ……………………..
   a. What are your preferences when eating out?

      ………………………………………………………………………………........
      ....

7. How often do you buy take-away food? ……………………………………….
   a. What are your take-away preferences? ………………………………...

      ……………………………………………………………………………

8. What type of milk do you use?

- ☐ Full Cream (approx 4% fat)
- ☐ Reduced fat (2% fat)
- ☐ No fat/Skim
- ☐ Other..

9. What, if any, type of cheese do you use?

- ☐ Do NOT normally eat cheese
- ☐ Standard block/ sliced cheese
- ☐ Reduced fat i.e. 25% reduced fat
- ☐ Low fat cheese (< 10-15g fat/ 100g)

10. What type of bread do you use? ………………………………………………..

11. Do you use margarine on bread/ toast? YES/ NO

    a. If so, how do you spread it?

    - ☐ Thinly (less than a teaspoon per slice)
    - ☐ Medium (~ 1 teaspoon per slice)
    - ☐ Thick (> 1 teaspoon per slice)

12. How many pieces of fruit do you eat a day? …………………………………...

13. How many meals a day include vegetables (cooked or salad)? ………………..

    a. What dressings, if any, do you add to vegetables and salads? ……………………..

14. How often do you have the following:

Fried food	…../week	Crumbed/battered food	….. /week
Roasts	…../week	Stir-fries	…../week

15. How much of the following foods do you have each week?

Biscuits	…../week	Cakes/slice	…../week
Ice cream	…../week	Chocolate	…../week
Lollies	…../week	Chips/corn chips	…../week
Nuts	…../week	Dried fruit	…../week

16. Which of the following do you drink each day and how much?

Drink *Quantity*

- ☐ Water …………………………………..
- ☐ Tea …………………………………..
- ☐ Coffee …………………………………..
- ☐ Soft Drink (Standard or diet)………………………………..
- ☐ Cordial/juice …………………………………..
- ☐ Sports drinks …………………………………..
- ☐ Other (specify) …………………………………..

17. Do you drink alcohol? YES/ NO

a. If so, how much per week

- ☐ Beer (heavy or light) …………………………………..
- ☐ Wine …………………………………..
- ☐ Spirits …………………………………..
- ☐ Other …………………………………..

Appendix 12. Weekly status check

Weekly Status Check

Participant_______________
Date_______________
Week #_______________
Telephone/in person/email

During the ***past week*** *have you had any of the following?*

	Yes	No
1. Acute illnesses Specify________________________________ ______________________________________	❐	❐
2. Change in medication (prescribed, over-the-counter, herbal, nutritional supplement) Specify _____________________________ ____	❐	❐
3. Visits to a health care professional Kind_________________________ Indication_____________________ Treatment_____________________	❐	❐
4. New physical, mental, or emotional symptoms of any kind Describe:______________________________ ______________________________________ ______________________________________	❐	❐
5. Injury Number________ Circumstance(s)_______________________	❐	❐
____________________________________	❐	❐
6. Have you attended all exercise sessions? If not, number attended__________________ Reason for missed session(s)______________ ____________________________________	❐	❐
7. Aside from the intervention, have you changed your exercise habits? If so, please describe_______________________ ____ ____	❐	❐
8. Have you changed your dietary habits? If so, please describe________________________ ____ ____	❐	❐

9. Other Questions or Comments:

____

____

____

____

Comments (researcher):

- ❑ protocol completed
- ❑ not completed due to death
- ❑ not completed due to refusal, drop-out or loss to follow-up
- ❑ not completed due to medical illness or incapacity
- ❑ not completed due to examiner failure or error
- ❑ not completed due to other:___________________________________